THE GEOLOGY OF THE

ROTOKOHU COAL MEASURES,

INANGAHUA VALLEY, BULLER.

A thesis
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FRONTISPIECE. Mulligans Mine at Fletcher Creek provides excellent exposure of the base of the Donkey Member.

ABSTRACT

The late Altonian to Waiauan Rotokohu Coal Measures formed as a fault controlled, rapidly subsiding fan-delta/delta sequence. The coal measures gradationally overlie rapidly shallowing-upward Waitakian to late Altonian sediments of the marine Inangahua Formation, and are unconformably overlain by Opoitian to Waipipian shallow marine to marginal marine sediments of the Giles Formation.

Three members are recognised within the coal measures:

a) the late Altonian to Clifdenian (?) Thomson Member occurs north of Inangahua Landing, and is interpreted as a marine influenced lower delta plain environment.

b) the late Altonian to Waiauan (?) Camp Member occurs north of McMurray Creek, and is interpreted as a humid alluvial fan characterised by gravel-dominated "Scott-type" channel sediments, and locally thick sequences of fine grained overbank sediments interbedded with thick conglomeratic crevasse-splay deposits.

c) the late Altonian to Waiauan (?) Donkey Member occurs in the southern Inangahua Valley, and is interpreted as a parallic alluvial plain characterised by low sinuosity, predominatly sandy rivers, and thick low sulphur coal.

Microlithotype and maceral analyses suggest that Rotokohu coals were predominantly formed from "woody" vegetation under telmatic (i.e. periodically inundated) conditions. Five reactives-rich, inerts-poor coal types are recognised, and are related to possible paleoenvironmental settings.

Coal type variation in exinite content and vitrinite chemistry appear to be major influences on volatile matter yields and specific energy, while variations in vitrinite chemistry are interpreted as a major influence on vitrinite reflectance. Vertical and lateral rank variations, weathering, and a possible variable marine influence are also probable influences on the analytical properties of the outcrop coal samples used in this investigation.

Syngenetic mineral matter in Rotokohu coals consists predominantly of detrital quartz, kaolinite and locally muscovite, and dominates the ash mineralogy of most samples. Organically bound elements, Ca, Mg, Na and Al are a major influence on the ash mineralogy of some low ash samples. Early diagenetic, low temperature silicification is relatively common, and is locally a major influence on the mineral matter content of some samples.

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CHAPTER ONE

INTRODUCTION

1.1 GENERAL SETTING

i) Location and Size

The Rotokohu Coal Measures crop out within the Inangahua Valley, on the West Coast of the South Island (Figure 1.1). The study area comprises approximately 100 km^2, forming a 2 to 3km belt extending from Giles Creek in the south-west, north along the western margin of the valley to Inangahua Landing. North of Inangahua Landing the size of the study area rapidly increases, incorporating most of the valley bottom from east of the Inangahua river, to the base of the Brunner Range (Figure 1.1), and extending north of the Buller River into the Welshman Pakihi/Thomson Creek area.

ii) Population and Access

Reefton is the main town in the Inangahua Valley (population 1,287; New Zealand Automobile Association pers. comm.), while Inangahua Camp with a population of some two dozen or so, is the next most populous centre. All other centres shown on maps are little more than a collection of 3 to 4 homesteads, or are no longer occupied.

Access to the study area is relatively good on a regional scale. State Highway 69 provides sealed access within the Inangahua Valley between Reefton and Inangahua Junction. State Highway 6 links Inangahua Junction with Westport in the west, and Murchison in the east, while State Highway 7 provides access to Greymouth in the south-west and Springs Junction in the east.

Further transportation is provided by the Stillwater-Westport railway line, which parallels State Highway 69 from the Buller River south to Reefton. Coal loading facilities for the railway are available at Inangahua Junction, Cronadun, Reefton, and have recently become available at Maimai.

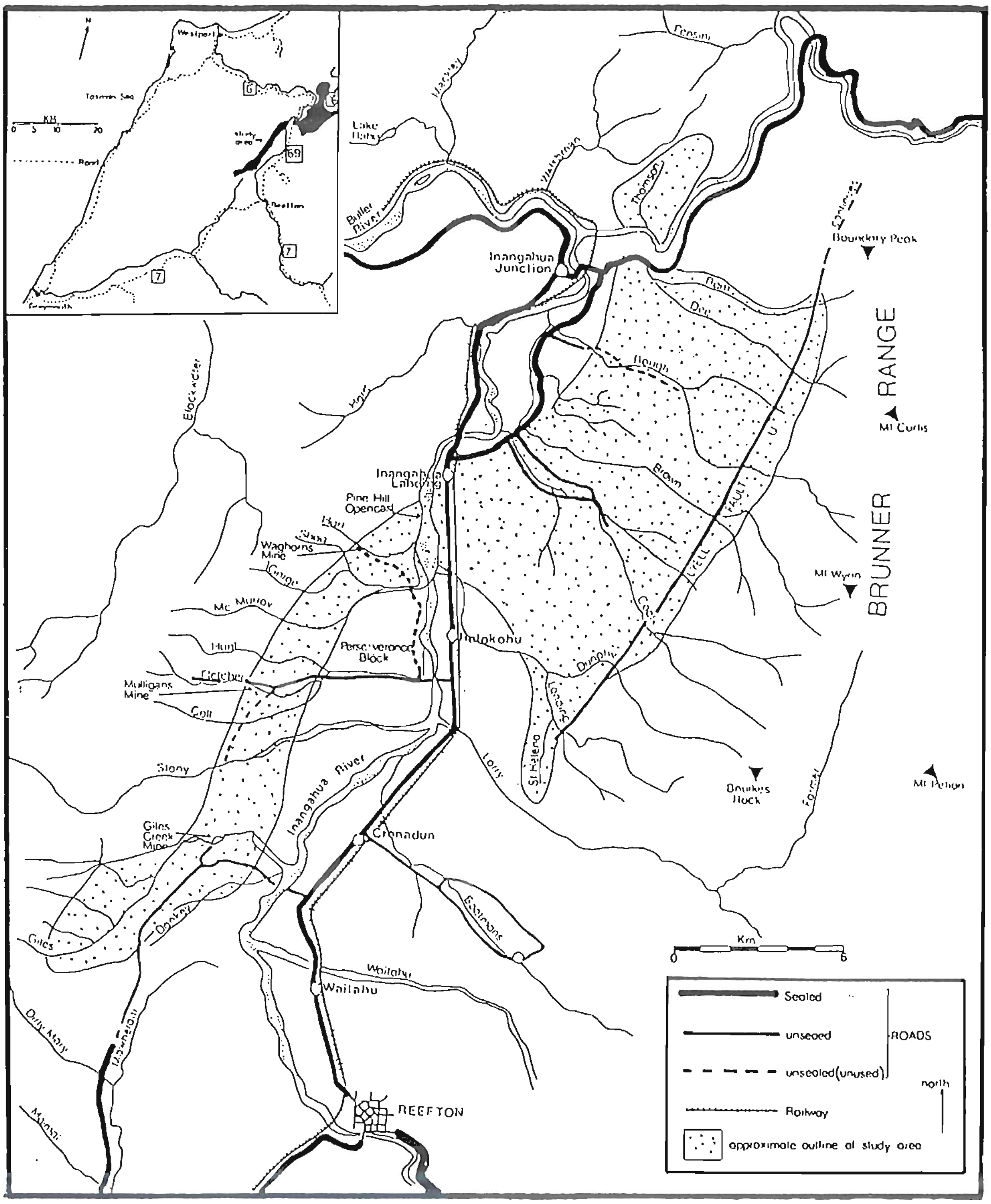


Figure 1.1: Location diagram of the study area showing access routes and localities mentioned in the text.

Access within the study area is poor away from the main transportation lines. Access to the western side of the Inangahua River between Stony River and Inangahua Landing (Perseverance Block) can only be achieved by fording the river during periods of low flow, or by using the foot bridge at Fletcher Creek. Access within the Perseverance Block is via a well maintained unsealed road to Burley's Opencast (mining Brunner Coal Measures), supplemented by disused forestry roads providing limited motor-bike access, although most creek sections are accessible only by foot. An unsealed forestry road extending from Maimai Road, provides good access to the Giles Creek Mine area. North of Inangahua Landing access is by foot only for all creek sections except Coal Creek.

iii) Climate, Vegetation and Physiography

The topography of the Depression clearly reflects the geology, with well indurated pre-Tertiary basement forming the rugged bush clad mountain ranges which define the valley margins. The western boundary of the valley is defined by the Paparoa Range which consistently attains heights in excess of 1200m south of the Buller river (Nathan 1978a), and forms a major physiographic divide between the coastal lowlands and the Inangahua Valley. The Brunner and Victoria Ranges define the eastern margin of the Valley, rising to a height of 1413m at Mt Wynn, and separates the Inangahua Valley from the Murchison/Maruia valleys to the east.

Less well indurated Tertiary sediments crop out within the valley bottom, generally younging towards the valley centre. Resistant Nile Group limestone beds form a prominent erosional escarpment extending from the Buller River south to the upper Giles Creek area. Friable Miocene to lower Pleistocene sediments underlie the low lying central valley, and are always poorly exposed. Aggradation and degradation during late Quaternary glaciations produced a series of prominent glacial terraces which dominate the geomorphology of the valley bottom (Figure 1.2).

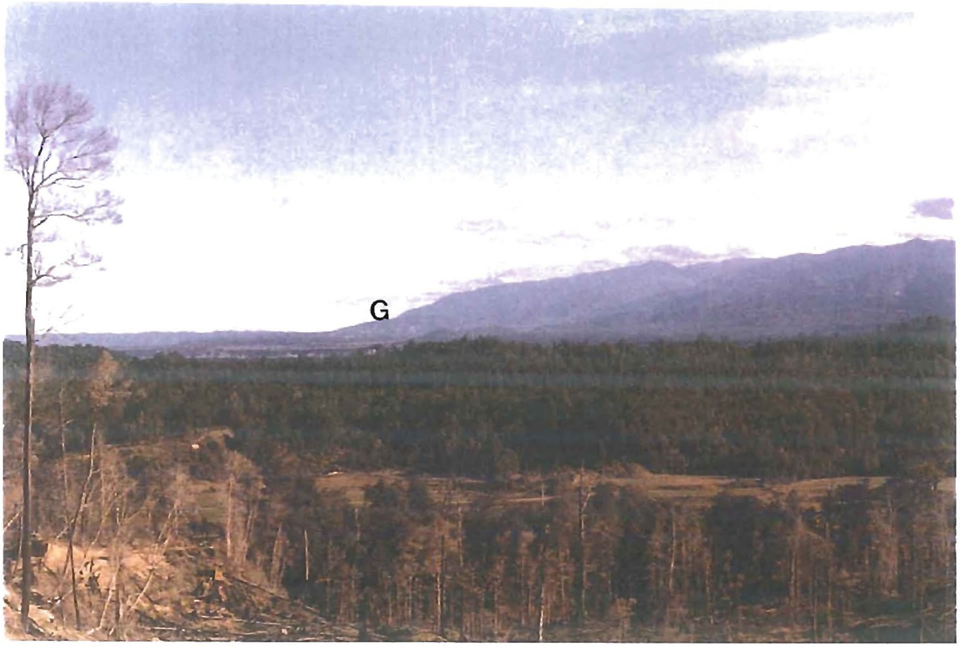


Figure 1.2: General view looking south from Coal Creek to Giles Creek (G). Nile Group sediments form a prominent escarpment at the base of the Paparoa Range, while Quaternary glacial surfaces dominate the subdued topography of the valley bottom.

The northerly flowing Inangahua River dominates the drainage pattern within the Inangahua Valley. The river-bed occupies the low-lying central valley, and is fed by a series of tributaries, of varying size, which drain the bounding ranges. The Inangahua River merges with the westerly flowing Buller River in the northern Inangahua Valley, near Inangahua Junction.

The climate of the Inangahua Valley is strongly influenced by the geomorphology. The rugged Paparoa Range isolates the valley from the moderating influence of the Tasman Sea, resulting in hotter summers and colder winters relative to coastal areas. The steep ranges form a strong climatic inversion which commonly results in a dense fog occupying the valley bottom, often persisting to late morning during summer, and mid-afternoon during winter months. Rainfall is generally evenly distributed throughout the year, being of the order of 2000mm per annum in the valley bottom, but is substantially more in the ranges (Suggate 1957).

Beef and sheep grassland farms are developed locally on recent river and low-level glacial terraces in the central valley. Pakihi swamps are commonly developed on high level glacial terraces, but much of the field area is covered in thick beech and podocarp forest, restricting field work to poorly exposed creek sections and the occasional road cutting.

1.2 PREVIOUS WORK

The Geology of the Inangahua Valley was initially mapped by Henderson (N.Z.G.S. Bull. No 17, 1917) at a scale of 1 inch to 1 mile. Henderson recognised the existence of mid Miocene deltaic sediments within the Inangahua Valley, but was unable to accurately subdivide these sediments on either lithostratigraphic or biostratigraphic grounds. Consequently Henderson's map suffers from inaccurate correlations, and relied on a complex fault pattern to explain the outcrop distribution that he proposed.

Henderson separated the coals of the Reefton Subdivision into a series of hierarchical groups on the basis of their different analytical properties. Each group was primarily thought to reflect the geological age of the coal, and secondly the spatial distribution. Mid Miocene coals at Camp and Giles Creek were shown to have distinctive analytical properties, and were classified as mid to late Miocene Inangahua delta beds. Unfortunately Henderson incorrectly correlated high sulphur mid Miocene coals at Thomson Creek with high sulphur Eocene (Brunner) coals outcropping in the Flaxbush Creek area, and this was to remain the accepted correlation for another 50 years.

During the mid-1940's to early 1950's a series of geological investigations were undertaken to evaluate the coal resources of the Inangahua Valley. Gage and Wellman (1944) produced a scathing report on the opencast potential of two thick outcrops of mid Miocene coal at Giles Creek. On the basis of:

a) the marked differences in interseam sediments at the two exposures,
b) the apparent lenticularity of the seam present in the lower outcrop (shown in this thesis to result from the regional Wanganui unconformity),
c) the large, unexposed area separating the two outcrops (approximately 1.5km) and,
d) the limited potential for rise coal, given the low-lying nature of the area in which the coal measures crop out;

Gage and Wellman concluded that the outcrops represented two separate and extremely lenticular coal seams. On this basis they recommended that the Giles Creek area was unsuitable for opencast mining, a conclusion which is disputed in this thesis.

Suggate and Wellman (1949) produced a short report on the Fletcher Creek Coalfield. The Brunner Coal Measures were the principal target of this report, with Miocene to early Pliocene sediments shown simplistically as continuous belts of sediment, with constant thickness south of Inangahua Landing. Suggate and Wellman considered that mid Miocene coal measures may contain a single thick (7m) coal seam at Hart Creek, but virtually no coal south of Shag Creek.

The discovery of Waipipian macrofossils at a number of localities within the Inangahua Valley during the late 1940's enabled the mid Miocene coal measures to be consistently separated from younger Old Man Gravels for the first time. Wellman (1950) utilised this discovery in his revision of the Cretaceous/Tertiary stratigraphy of the Inangahua Valley, and was consequently able to define the general structure and outcrop pattern more accurately than previous workers. Wellman's broad lithostratigraphic correlation of the Grey-Inangahua Valley was to form the basis of all subsequent correlations. However, Wellman still accepted Henderson's incorrect correlation of high sulphur mid Miocene coal at Thomson Creek as Brunner Coal Measures, and continued to map upper Tertiary sediments south of Inangahua Landing as a conformable sequence with constant bed thickness.

Suggate's Reefton Bulletin (No 56, 1957) maintained the assumption of constant bed thickness for upper Tertiary sediments on the south-western side of the Inangahua Valley, and was forced to invoke a complex fault relationship to adequately explain the outcrop data at Giles Creek. The Reefton map revealed a widespread Opoitian unconformity on the eastern margin of the Inangahua Valley, and suggested an easterly facies change within lower Wanganui sediments, from shallow marine at Giles Creek to non-marine in the Reefton area.

Formal lithostratigraphic nomenclature for the Buller/North Westland region was proposed by Nathan (1974), and was used as the basis of the lithostratigraphy shown on the Buller-Lyell (Nathan 1978a, Figure 1.3) and Greymouth (Nathan 1978b) Sheets. The Rotokohu Coal Measures were defined as late Altonian to Waipipian, non-marine sediments which cropped out extensively in the Grey-Inangahua Depression.

The proposed stratigraphic relationships on the Buller-Lyell Sheet (Nathan 1978a) show the Rotokohu Coal Measures to overlie the Inangahua Formation, conformably in the northern, and disconformably in the south-western Inangahua Valley. Nathan recognised the presence of a Waipipian unconformity in the Hunt/McMurray Creek area, where a problematic stratigraphic relationship is shown, but was unable to correlate this surface throughout the rest of the Grey-Inangahua Depression.

A further major unconformity was interpreted by Nathan in the Landing Creek area, where "Rotokohu Coal Measures" were shown to unconformably overlie Nile Group sediments and Paleozoic basement. The precise age and stratigraphic relationships of these "coal measure" sediments at St Helena Creek is unclear from Nathan's map, but a probable Opoition/Waipipian age is suggested through correlation with similar sediments mapped by Suggate (1957) further south. The Buller-Lyell Sheet was the first map to correctly correlate coal measures in the Thomson Creek area with Miocene coal measures mapped further south.

1.3 REGIONAL GEOLOGY

The geology of the Inangahua Valley can be broadly subdivided into two parts (Figure 1.4),

a) pre-Tertiary basement forming the rugged mountain ranges which define the valley, and
b) less well indurated Tertiary to Quaternary sediments which underlie the low-lying valley bottom.

Pre-Tertiary basement on the eastern side of the valley is comprised of coarse-grained muscovite granite (Dunphy

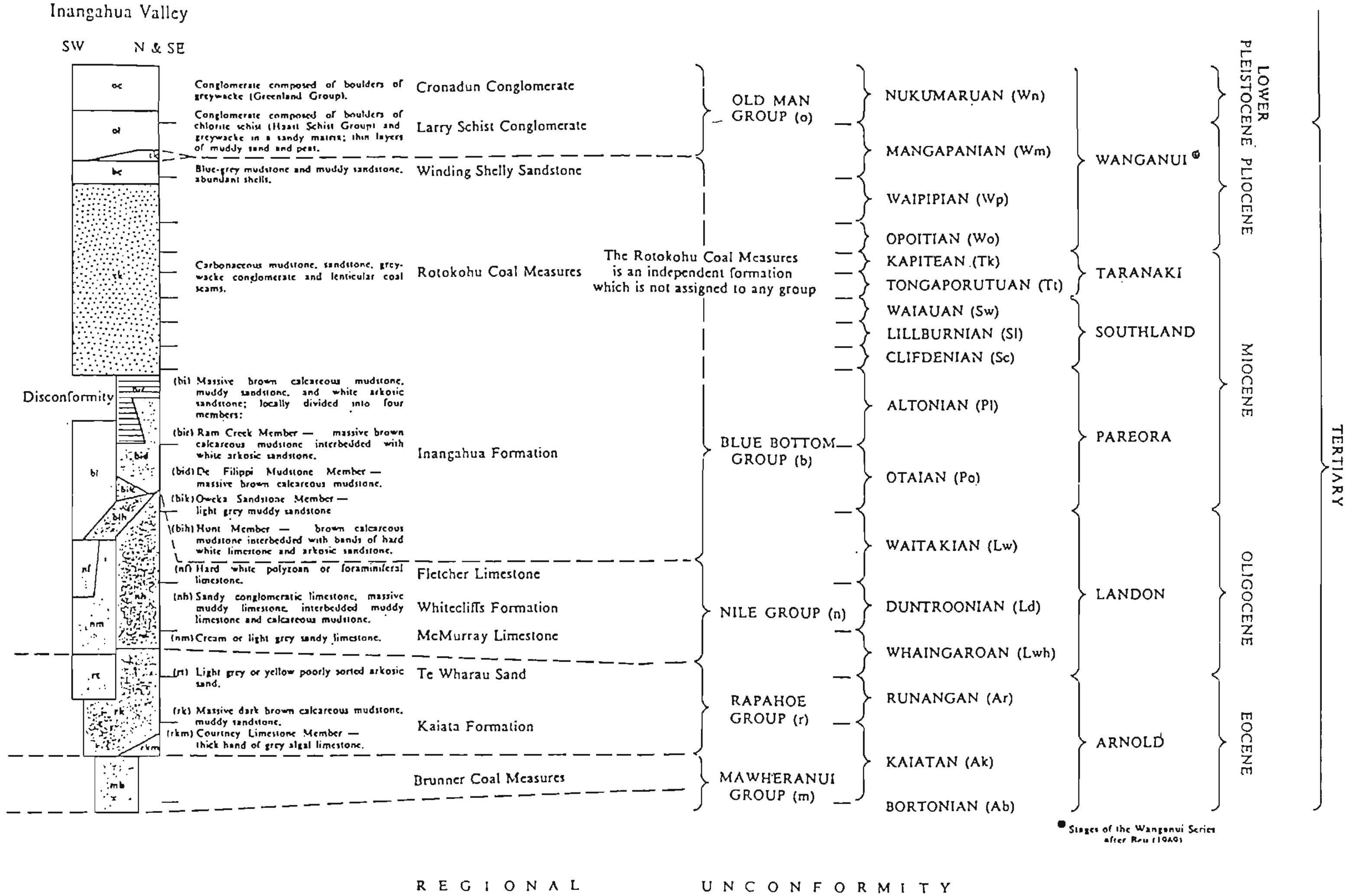


Figure 1.3: Lithostratigraphy of the northern Inangahua Valley proposed by Nathan (1978a), based on Nathan (1974).

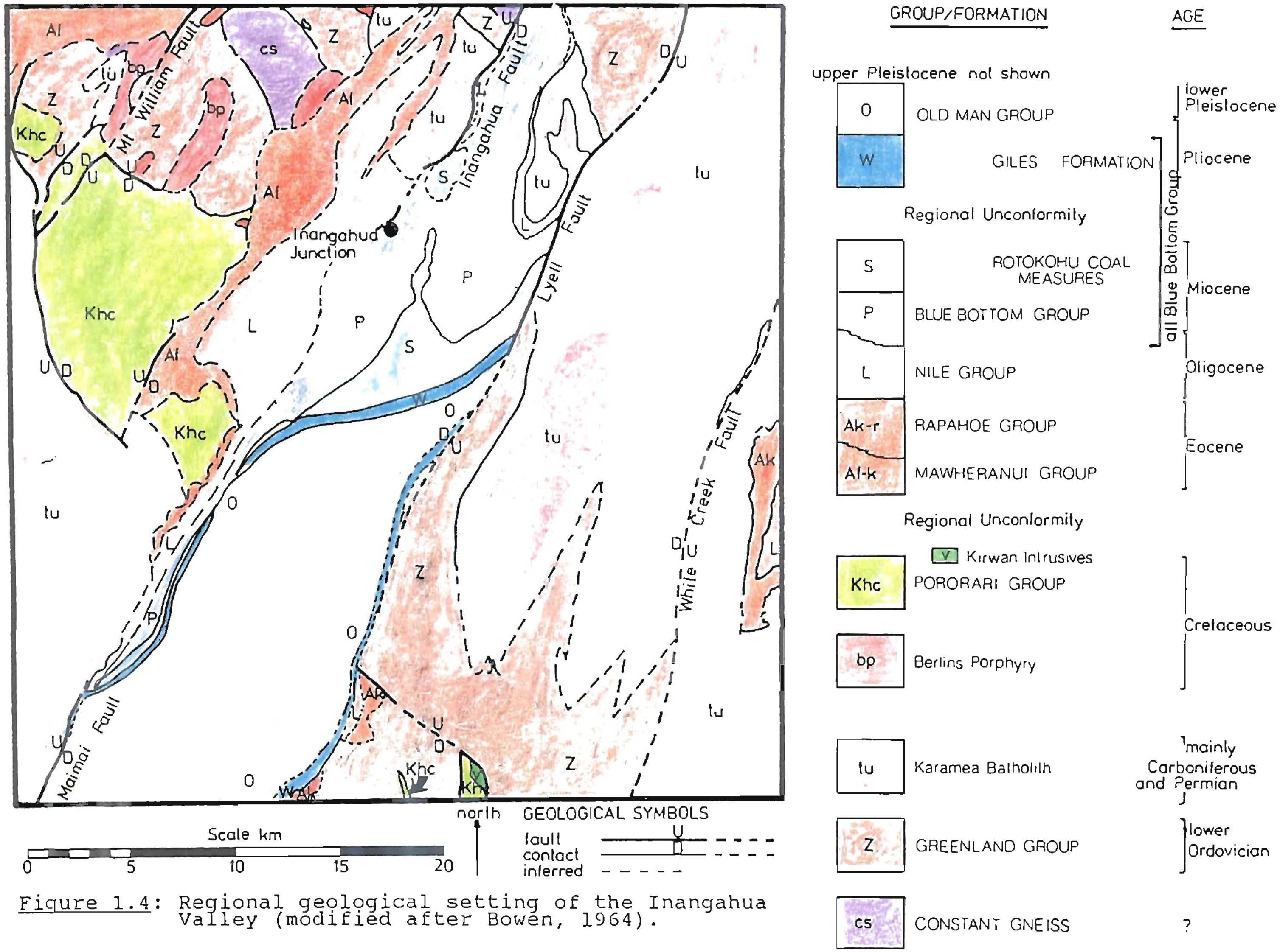


Figure 1.4: Regional geological setting of the Inangahua Valley (modified after Bowen, 1964).

Granite; Nathan 1978a), and well indurated greenish-grey, Greenland Group "quartzose greywacke and argillite" (Nathan 1978a). A 1.25km biotite hornfels metamorphic aureole characterises the Greenland Group/granite contact, and is well defined by Nathan (1978a).

Pre-Tertiary basement on the western side of the valley is comprised of unfoliated biotite granite and granodiorite south of Fletcher Creek, and Cretaceous non-marine Pororari Group sediments in the north (Nathan 1978a). Pre-Tertiary basement was essentially not mapped during this thesis, and the interested reader is referred to detailed works for a more complete discussion (Wellman 1950, Suggate 1957, Laird and Shelley 1974, Nathan 1978a, Nathan and others 1986).

The base of the Tertiary sequence within the Inangahua Valley is marked by a major regional unconformity. Lower Tertiary sediments within the valley record the broad transgression which characterises lower Tertiary sequences of the Buller/North Westland region. Kaiatan Brunner Coal Measures of the Mawheranui Group occur at the base of the Tertiary sequence north of Stony River, forming a distinctly angular, unconformable onlap relationship with pre-Tertiary basement, successively truncating highly leached Pororari Group sediments, highly leached granite, and fresh granite in the Fletcher Creek area.

The Mawheranui Group is conformably overlain by and locally interdigitates with (in the Fletcher Creek area) Kaiatan to Whaingaroan, clastic, shallow marine sediments of the Rapahoe Group. South of Coll Creek (map 3 back pocket, and Nathan 1978a), shallow marine, medium to coarse sandstone (Te Wharau Sand; Nathan 1974) of the Rapahoe Group directly overlies fresh, coarse-grained granite.

The Rapahoe Group is conformably overlain by Whaingaroan to early Otaian, marine limestones and highly calcareous sediments of the Nile Group, which are inferred to represent a period during which the supply of terrigenous material was minimal (Nathan and others 1986). Highly calcareous Nile Group sediments are conformably overlain by, and interdigitate with Waitakian to Altonian, fine grained clastic marine sediments of the Blue Bottom Group (Nathan 1974).

Within the Buller/North Westland region as a whole, the Blue Bottom Group ranges in age from Waitakian to Waipipian, and represents a broad regressive sequence which was terminated by the influx of coarse, allochthonous conglomerates of the Old Man Group. Within the Inangahua Valley, Altonian sediments of the Blue Bottom Group represent a rapidly shallowing regressive sequence which is conformably overlain by predominantly terrestrial sediments of the Rotokohu Coal Measures.

Published literature (Nathan 1974, 1978a, 1978b, 1978c, and Nathan and others 1986) considers the Rotokohu Coal Measures to range in age from late Altonian to Waipipian, and to extend from the northern Inangahua Valley south into the Greymouth area. Both these interpretations are disputed in Chapter 2 of this thesis.

1.4 MINING ACTIVITIES TO DATE

The Rotokohu Coal Measures have been mined intermittently on a small scale since the turn of the century, although actual coal production from the formation has been negligible. Reliable production figures are only available for Mulligans Mine (also known as Fletcher Creek Opencast), with most of the early mines not keeping records, or records have been lost (W. Brazil, Inspector of Coal Mines, Westport, pers. comm.).

At the turn of the century "a seam varying from 2-3 feet in thickness was stripped and removed to the extent of an acre" in the Thomson Creek area (Henderson 1917, p207). This high sulphur coal was then sluiced down Thomson Creek, and was used by the Mokoia dredge which worked the Three Channel Flat area between 1900 and 1911.

Pine Hill Opencast produced "a few hundred tonnes of coal" (Nathan 1978, p27) during the 1950's, from a vertically dipping, 7.5m, low sulphur, low ash coal seam which crops out in the high level glacial terrace on the western side of the Inangahua River near Hart Creek. A new unsealed road has recently been driven into the old mine area, and the current lease holder (Mr B. Waghorn) is hopeful of resuming mining shortly.

A small tonnage of coal was won from a vertically dipping seam at Waghorn's Mine, Hart Creek, during the early 1970's (B. Waghorn pers. comm.). No reliable production figures are available, and production ceased in 1975 when the Perseverance bridge was washed out.

Mulligans Mine produced 29,495 tonnes of coal over 8.5 years (W Brazil, pers. comm.), by both opencast and underground methods from a seam of variable thickness which cropped out in Fletcher Creek. Production ceased in March 1975 with the loss of the Perseverance bridge.

In late 1984 mining commenced at Giles Creek on the first thick coal outcrop, about 3km upstream from the Inangahua River. The immediate northern extent of this outcrop is limited by the presence of the regional Wanganui unconformity, which is distinctly angular in this area (see map 3, and Chapter 2 for discussion of stratigraphy). Prospecting is continuing on the river terrace south of the mine.

A prospecting license is currently held by Mr G. Fletcher for the Camp Creek area, but little work has been done to date.

A fully cored drill hole was recently completed in September 1986 at Giles Creek, as part of the New Zealand Coal Resources Survey (DH 118, GR. K30 010064*; a complete log of the coal measure sequence is included in Appendix 12). Approximately 16.90m of low sulphur coal, of variable ash content was intersected, occurring within four seams. The results of this drill hole are due to be published shortly by Mines Division, Resource Management and Mining Division.

[*<u>All grid references are for NZMS 260 metric map series, unless otherwise stated</u>.]

1.5 THESIS OBJECTIVES

In view of the large field area (approximately 100 km^2), it was anticipated that the project would primarily be a regional appraisal of the Rotokohu Coal Measures within the Inangahua Valley. Consequently, the principal objectives of this thesis are as follows:

1) To remap in detail the Rotokohu Coal Measures within the Inangahua Valley. From this detailed mapping it was hoped to establish a stratigraphic framework which would aid future work on the upper Tertiary to lower Quaternary sequence within the Grey-Inangahua Depression.
2) To characterise the coal petrography, mineralogy and geochemistry of coal seams within the Rotokohu Coal Measures.
3) To classify coal samples into specific coal types on the basis of both their organic and inorganic constituents.
4) To relate the coal types recognised to specific depositional environments, and to attempt to establish a depositional model for the coal measures based on sedimentological and coal type characteristics.

The majority of outcrops within the field area were restricted to small creek exposures, commonly comprised of less than 4-5 metres of continuous exposure. The poor exposure created difficulties for both detailed sedimentological studies, and stratigraphic correlations. Indeed, the poor quality of exposure, the apparent lithologic similarity between formations, and the lack of sufficient age control at critical outcrops, are the major reasons for the more simplistic stratigraphic subdivisions proposed by previous workers for the mid Miocene to early Pliocene stratigraphy of the Inangahua Valley.

1.6 METHODS

1.6.1 Field Work

Field work was undertaken over approximately 12 weeks between late January to early May 1985. The majority of this time was spent traversing creek sections, measuring small creek exposures, and collecting coal samples. Additional trips to the field were undertaken during 1986, accompanied by Mr. Mark Eggers (University of Canterbury), Dr. Murray Cave (Mines Division), Mr Simon Nathan and Dr. Dallas Mildenhall (NZGS), Dr. Romeo Flores and Ms Jean Weaver (USGS), and Dr. Jane Newman (University of Canterbury).

Mapping was undertaken using low level aerial photographs and NZGS base maps, both at a scale of approximately 1:15,840. Additional aerial photographs at a scale of approximately 1:10,000 were obtained for the Giles Creek area from the New Zealand Forest Service, Reefton. Roads and appropriate outcrop data were transferred from the Giles Creek aerial photographs to final maps using a radial line plotter. All field data was transferred to NZMS 260 1:50,000 compilation sheets (at a scale of 1:25,000), obtained from the Department of Lands and Survey, Wellington, and these sheets form the base for the geological maps provided in the map pocket.

All stratigraphic sections were measured by tape and compass traverse, or tape measure. Field descriptions of sedimentary units more or less follow the guidelines and terminology of Lewis (1981). Colour is described using the Geological Society of America colour chart. Grain size descriptions are based on field estimations, using a hand lens and comparator. The term mud is used in the sense proposed by Folk et al. (1970) for field description of fine grained sediments, although the presence of significant quantities of silt is noted.

Composition determinations are based on field estimations using the classification system proposed by Folk et al. (1970). Detailed provenance studies were outside the objectives of this thesis, and the interested reader is referred to more detailed studies by Smale and Langer (1980), and Watters

(1982) on the mid to upper Tertiary sequence in the Buller/Murchison region.

Lithological symbols and abbreviations on measured sections in Chapter 2 more or less follow the "Revised Guide to Recording Field Observations In Sedimentary Sequences" (Andrews 1982), while lithological symbols used in Chapter 3 follow the graphic code presented in Appendix 2.

All coal samples were obtained from creek or mine exposures, with care taken at all times to provide a representative, relatively unweathered sample. A complete sample list is provided in Appendix 1, with sample character (i.e. channel, or grab/spot-sample) and locations (given as NZMS 260 grid references) indicated with results of maceral analyses in Appendix 5.

Palynological samples were collected for Mr. Simon Nathan from Coal and Giles Creeks, and are shown on appropriate sections, using NZGS fossil record file numbers.

a) Fletcher Creek Survey Method

The Fletcher Creek Mine was surveyed in January 1986 by Mr M.J. Eggers, with the assistance of the author, using a Nikon NTD-3 uniaxial theodolite-distancemeter. All major topographical features (springs, terrace scarps etc), and major contacts were surveyed. The remaining lithostratigraphic and structural data were mapped on completion of a topographical map from the survey data. Reduced levels are relative to Station 1, which was given an assumed height of 200 metres (estimated from NZMS 260 topographical map L30).

1.6.2 Laboratory Work

a) Coal Petrography

i) Maceral analyses

Maceral analyses were performed on 67 particulate coal mounts using a Leitz Ortholux II incident light microscope equipped with a 50x oil immersion lens, 10x ocular lenses, an Orthomat-W camera, and a Swift automatic point counter. Techniques used in the preparation of particulate mounts are outlined in Appendix 4. Results of maceral analyses are tabulated in Appendix 5, with all sample numbers referring to official University of Canterbury sample numbers, unless otherwise stated.

During point counting a minimum point to point spacing of 0.3mm, and a line to line spacing of 1mm were employed at all times. In accordance with I.C.C.P (International Committee For Coal Petrology 1971) recommendations, only one point was counted per grain. A minimum of 500 <u>maceral</u> points were counted for all samples except for very high ash samples (11817, 11818, 11838, 11843, 11851 and 11854), for which <u>maceral + mineral matter</u> counts were at least 500.

Nathan (1978a) classified the Rotokohu Coal Measures as sub bituminous C and B (American Society For Testing Materials [ASTM] classification). On this basis, and in accordance with I.C.C.P. recommendations, black coal petrographic nomenclature was used in both maceral and microlithotype analyses. The individual macerals recognised in this thesis are shown in Figure 1.5. Discussions on the origin and definition of maceral terms are provided by Stach et al. 1982, and the International Handbook of Coal Petrography 1971.

Maceral terminology in this thesis follows these guidelines, and for convenience many submacerals are specifically defined in the text. Telinite was not included in maceral analyses because very few macerals were observed to consist solely of cell wall material. The term telocollinite was consequently expanded to include all large (>10um) macerals with observed or inferred tissue structure.

To facilitate comparison of samples, black coal terminology was also used on 3 lower rank Giles Formation coal samples (possibly Lignite A; ASTM classification using outcrop samples, see Chapter 6 for discussion of the problems associated with rank assessment in low rank coals) collected from the Giles Creek area.

ii) Microlithotype analyses

Microlithotype analyses were performed in accordance with I.C.C.P. (1971) recommendations, using the same particu-

Group maceral	Maceral	Submaceral*	Maceral variety*
Vitrinite	Telinite	Telinite 1	Cordaitotelinite
		Telinite 2	Fungotelinite
			Xylotelinite
		Telocollinite	Lepidophytotelinite
		Gelocollinite	Sigillariotelinite
	Collinite	Desmocollinite	
		Corpocollinite	
	Vitrodetrinite		
Exinite	Sporinite		Tenuisporinite
			Crassisporinite
			Microsporinite
			Macrosporinite
	Cutinite		
	Resinite		
	Alginite		*Pila*-Alginite
			Reinschia-Alginite
	Liptodetrinite		
Inertinite	Micrinite		
	Macrinite		
	Semifusinite		
	Fusinite	Pyrofusinite	
		Degradofusinite	
	Sclerotinite	Fungosclerotinite	Plectenchyminite
			Corposclerotinite
			Pseudocorposclerotinite
	Inertodetrinite		

Figure 1.5: Summary of the macerals of black coals (from Stach et al. 1982).

macerals underlined are those recognised in this study.

late mounts and microscope equipment used for maceral analyses. The only additional equipment was a Kötter 20 point crossline graticule inserted in the microscope ocular. A total of 500 microlithotypes were counted for each sample, with the results expressed on a percentage basis (Appendix 6).

iii) Vitrinite Reflectance

Reflectance determinations were performed in late February 1986 on 30 samples using a Leitz Orthoplan-MPV2 housed in a temperature controlled room at Auckland University. The microscope was calibrated using standards of 1.24% and 0.545% reflectance, and Leitz immersion oil (R.I.= 1.5810). Five further reflectance determinations were performed in Wellington using the New Zealand Geological Survey Leitz Orthoplan-MPV2 system, and a garnet standard of 0.98% reflectance.

A manual stage is employed in both systems, but with care a line to line spacing of 1mm is readily maintained. Particulate samples were used for all reflectance determinations (see Appendix 4 for preparation method). The grains selected for reflectance determination were distributed throughout the sample, and only one measurement was performed on each grain, with generally a minimum of 75-100 measurements made on telocollinite macerals for each sample (except sample 11809=18 measurements).

Bireflectance exhibited by vitrinite macerals in low rank coals is very small (Stach et al. 1982, Diessel 1984). In such cases it is not necessary to measure $\bar{R}o$ max, the maximum reflectance exhibited by a maceral, as random reflectance provides an adequate approximation to $\bar{R}o$ max (Diessel 1984, Cameron et al. 1984). Random reflectance is the value obtained immediately on encountering the maceral, without rotating the stage to observe either the maximum or minimum values. Random reflectance ($\bar{R}o$ %) was measured for all Rotokohu samples.

b) Coal Mineral Matter

i) Petrography

Polished sections provide the most suitable means of studying the form and distribution of mineral matter within coals, but are of limited value for positive mineral identification. Both maceral and microlithotype analyses provided useful information on mineral matter, and the results are tabulated in Appendices 5 and 6. Microscope equipment, and methods are those outlined above.

A study of the mineral matter composition of Rotokohu coals under reflected light was restricted to the identification of one of three main mineral groups, quartz, clays and sulphides, with hematite present where sulphides have been weathered. Carbonate minerals were not detected in polished sections.

ii) Low Temperature Ashing and X-Ray Diffraction

The mineral matter composition of a series of 28 samples was determined using low temperature ash (LTA) and X-ray diffraction techniques. The low temperature ashing procedure used was that originally defined by Gluskoter (1965), with specific settings and refinements as used by Mr. N. Newman (University of Canterbury, pers. comm.).

A small quantity of coal was crushed to a fine powder, with approximately 2 grams of this powder spread thinly on a glass tray. The glass trays were then placed in a LFE Corporation LTA-302 low temperature asher, and ashed in an oxygen plasma for 1-2 days. Samples were stirred every 2 -3 hours during the ashing process to expose unoxidised surfaces.

The ashing technique slowly oxidises the organic fraction at temperatures of approximately 120-130^{0}C (never above 150^{0}C), and results in a residue of relatively unaltered mineral matter. However, even at these low temperatures some minerals can be affected by the oxidation process (Frazer and Belcher 1973, N. Newman pers. comm.).

On completion of the low temperature ashing process the residual ash was washed in distilled water, finely ground in an agate mortar, and then allowed to dry on a glass slide. The mineralogy of the ash was then determined using a Philips X-ray diffraction system.

Where the presence of swelling clays was suspected, samples were glycolated, and a second diffractogram was run to determine if any changes occurred in the d-spacing intervals. Detailed investigation of swelling clays was considered beyond the scope of this thesis.

Minerals present in LTA residues are tabulated in Appendix 9 with the ash percentage determined by CRA (Coal Research Association, Gracefield, Wellington.) from proximate analyses (where available). The relative abundance of individual minerals estimated from X-ray diffractogram peak heights is broadly indicated.

iii) High Temperature Ashing

A series of 16 samples were crushed to a fine powder, with a representative sub-sample of approximately 10 grams ashed at the British Standard temperature of 815^{0}C. The ash was then fused with a flux to form a glass disk, using the general methods of Norrish and Hutton (1969), with modifications after Harvey et al. (1973). Each glass disk was analysed using a Philips PW 1400 automatic sequential X-ray fluorescence spectrometer, and interelement correction (Norrish and Hutton) was carried out by on-line computer. Results were obtained for Mg, Na, Si, Al, S, P, Fe, Mn, Ti, Ca and K, all reported as weight percentage oxide on a loss on ignition-free basis, and are tabulated in Appendix 11.

iv) Scanning Electron Microscope

Mineral matter investigations using Scanning Electron Microscope (SEM) techniques were restricted to siliceous partings (samples 11882 and 11881). Sample preparation techniques are outlined in Appendix 13. The SEM system used was a Cambridge Stereoscan 250 Mk II housed in the Botany Department at the University of Canterbury.

CHAPTER TWO

STRATIGRAPHY

2.1 INTRODUCTION

A revision of the early Miocene to Pliocene stratigraphy of the Inangahua Valley is proposed in this thesis. The stratigraphic interval originally defined by Nathan (1974) as the Rotokohu Coal Measures (Figure 1.3) is subdivided into two formations, separated by a major regional unconformity. The lower formation is the essentially nonmarine late Pareora to late Southland Series Rotokohu Coal Measures, while the upper formation is the shallow marine to nonmarine Wanganui Series Giles Formation (Figure 2.1).

The Rotokohu Coal Measures are now subdivided into the Thomson, Camp and Donkey Members. The underlying late Landon to late Pareora, marine Inangahua Formation was formally defined by Nathan (1974), and included in the Blue Bottom Group. Nathan recognised four members in the Inangahua Formation north of Inangahua Landing, and this subdivision is extended south in this thesis.

One member and four lithofacies are informally defined in the Giles Formation. A possible depositional environment is proposed for the formation in this Chapter, while aspects of the Rotokohu Coal Measures are discussed in more detail in the following Chapters. A discussion of the overlying Old Man Group is included to complement the accompanying maps, and to justify the proposed revision of Group nomenclature.

Group nomenclature for the Buller/North Westland region was formally proposed by Nathan (1974), and has since been the subject of some controversy (Gage 1975, Lewis 1975, Carter et al. 1982). Nathan (1974) defined the Blue Bottom Group as "marine detrital sediments, mainly mudstone and muddy sandstone" ranging in age from upper Waitakian to Waipipian. The Rotokohu Coal Measures were considered to be late Altonian to

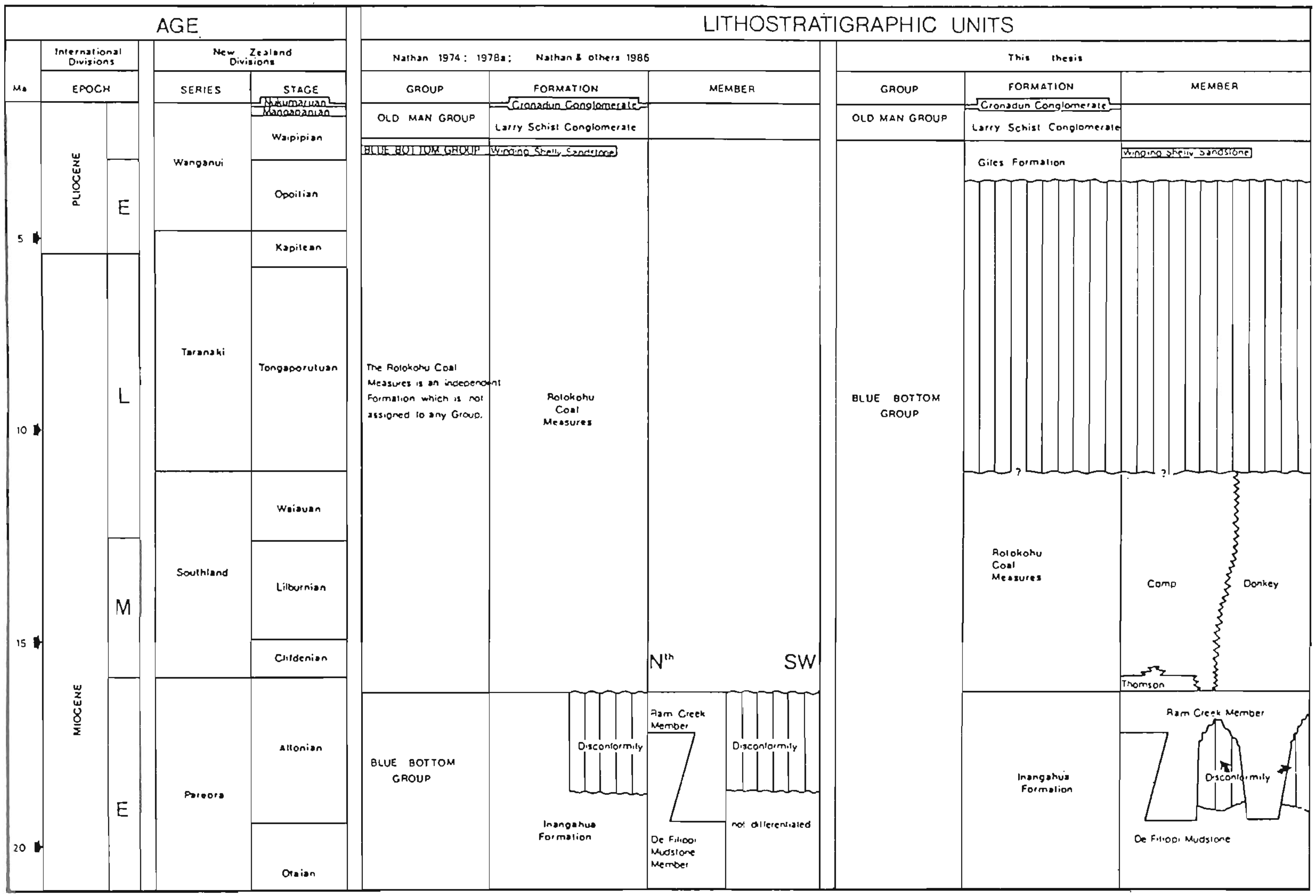


Figure 2.1: Early Miocene to Pliocene stratigraphy of the Inangahua Valley.

Waipipian, and were excluded from the Blue Bottom Group on the basis of their nonmarine character.

The overlying Waipipian to early Nukumaruan Old Man Group was defined as "nonmarine conglomerate and sandstone, locally interbedded with minor peat and glacial beds", although in the Inangahua Valley the base of the Group was defined by the incoming of Haast Schist derived clasts of the Larry Schist Conglomerate (Nathan 1974). The basis of this Group nomenclature is primarily genetic, and consequently more liable to criticism than a subdivision based purely on textural or compositional criteria.

Group nomenclature based on subjective genetic criteria is impractical within the Inangahua Valley, where locally derived Wanganui sediments (Giles Formation) overlie locally derived Southland sediments (Rotokohu Coal Measures). Similar criticisms have been stated by previous geologists (Gage 1975, Lewis 1975) who emphasised the difficulties which may be encountered in distinguishing between marginally marine and marginally nonmarine sediments in the field. Consequently it is proposed that both the Giles Formation and the Rotokohu Coal Measures be included within the Blue Bottom Group, with the incoming of schistose clasts of the Larry Schist Conglomerate defining the base of the overlying Old Man Group.

2.2 INANGAHUA FORMATION (Nathan 1974)

Nathan (1974) defined the Inangahua Formation as Waitakian to Altonian, grey-brown, marine, calcareous mudstone or muddy sandstone, widespread in the Grey-Inangahua Depression. The formation was locally subdivided into four members within the northern Inangahua Valley (Figure 1.3).

The basal Hunt Member is defined as late Waitakian to early Otaian, massive, brown, calcareous marine mudstone interbedded with thin beds of hard white foraminiferal or muddy limestone, and locally containing beds of white "arkosic" sandstone (Nathan 1974). The unit forms a continuous belt of sediment, of variable thickness, outcropping on the western side of the Inangahua Valley from Inangahua Junction in the north, south to Giles Creek (see Nathan 1978a, and map 3 of this thesis for the upper Giles Creek area).

The Oweka Sandstone Member is defined as mid Otaian, light grey, slightly calcareous, marine, muddy medium sandstone with scattered concretionary bands (Nathan 1974). The unit outcrops only locally near Oweka Bluff, and was not mapped during this thesis.

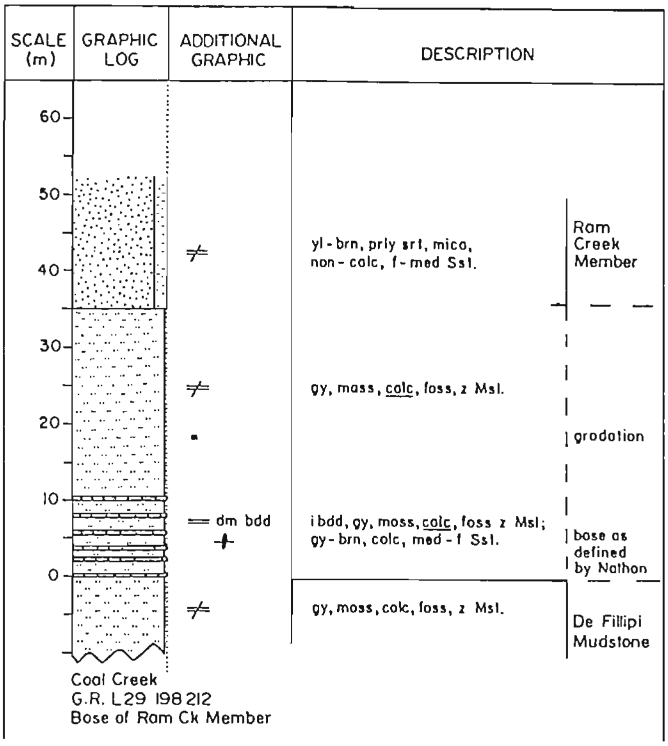
Nathan recognised two members within the upper Inangahua Formation north of Inangahua Landing, as follows:

a) De Filippi Mudstone Member; mid Otaian to mid Altonian, massive grey/brown, highly calcareous marine mudstone.
b) Ram Creek Member; early to late Altonian, massive white, "arkosic sandstone", interbedded with grey/brown, highly calcareous marine mudstone.

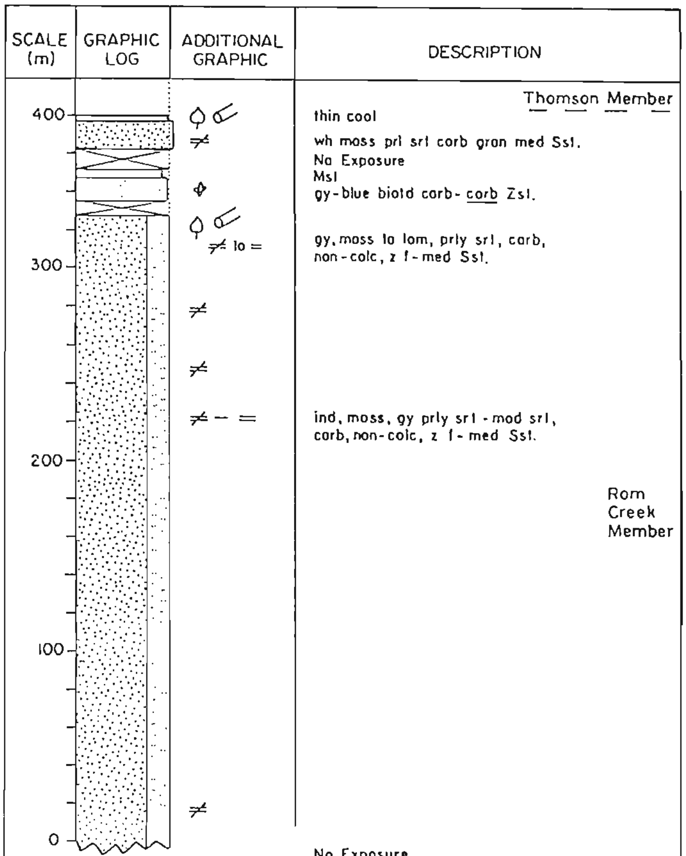
Formal definitions of both members are given by Nathan (1974), and are adopted in this thesis. The outcrop pattern of these two members observed during mapping for this thesis conforms to that shown by Nathan (1978a) for the area north of Inangahua Landing.

Coal Creek provides a well exposed reference section showing the vertical gradation between the De Filippi Mudstone and Ram Creek Members (Figure 2.2). A well exposed reference section for the Ram Creek Member occurs further north at Brown Creek, where approximately 400m (thickness scaled off field maps) of predominantly massive, carbonaceous, non-calcareous, silty fine to medium lithic feldsarenite is exposed (Figure 2.3).

A similar outcrop pattern of massive, highly calcareous marine mudstone, abruptly overlain by massive, non-calcareous, silty fine to medium sandstone occurs from Inangahua Landing south-west to Shag Creek, and from Hunt Creek south to Giles Creek. Stony River provides a representative reference section for the upper Inangahua Formation south of Inangahua Landing (Figure 2.4). The correlative of the upper De Filippi Mudstone is slightly coarser grained, and commonly



<u>Figure 2.2</u>: Measured section of the gradational contact between De Filippi Mudstone and Ram Creek Member (both upper Inangahua Formation) at Coal Creek.



<u>Figure 2.3</u>: Reference section for the Ram Creek Member (upper Inangahua Formation) at Brown Creek, (thickness scaled off field maps).

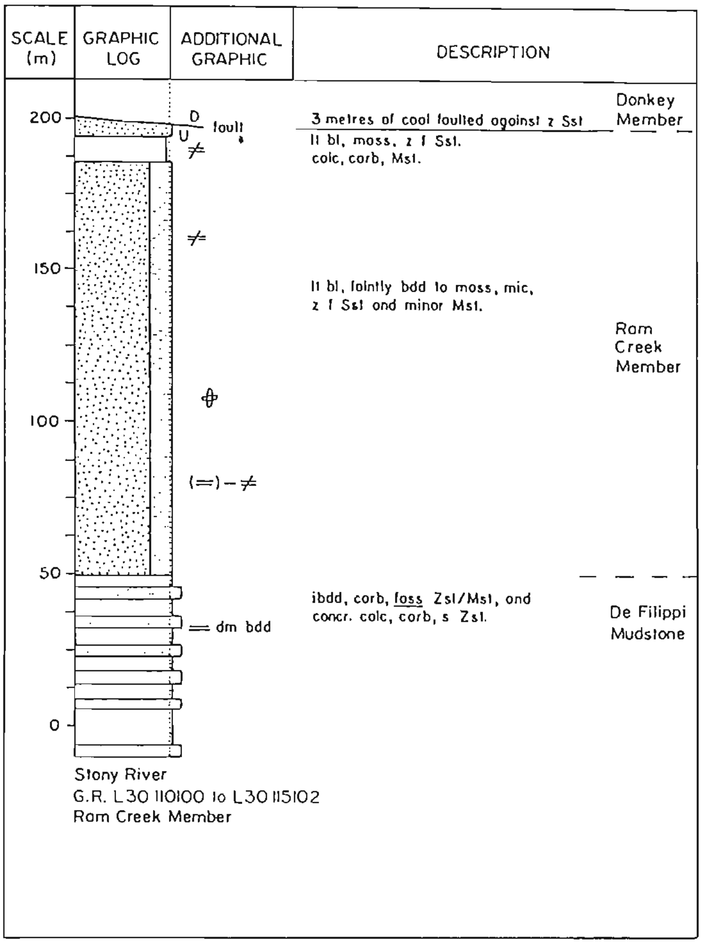


Figure 2.4: Measured section of the gradational contact between De Filippi Mudstone and Ram Creek Member (both upper Inangahua Formation), Stony River.

contains moderate to well developed decimetre thick beds of concretionary sandy siltstone south of Hunt Creek.

The stratigraphy proposed by Nathan for the upper Inangahua Formation north of Inangahua Landing is consequently extended south (Figure 2.5). Nathan (1978a) correlated sandstones at Inangahua Landing/Shag Creek and Fletcher Creek as Rotokohu Coal Measures, but on the basis of correlations suggested above, the sandstone at these locations is now assigned to the Ram Creek Member.

The Ram Creek Member in the upper Rough Creek area is distinctly different to the massive sandstone which characterises the member throughout most of the Inangahua Valley, predominantly comprising grey/brown, calcareous mudstone interbedded with minor bands of fine concretionary sandstone (Figure 2.6). The thickness and distribution of sandstone within the Ram Creek Member is interpreted as defining two centres of active sandstone deposition within the Inangahua Formation north of Inangahua Landing, and a further centre in the south at Giles/Stony River.

The disconformity said by Nathan (1978a) to lie at the base of the Rotokohu Coal Measures in the south-west is reinterpreted. The Rotokohu Coal Measures are observed to gradationally overlie the Ram Creek Member at all sections where the contact is exposed, with the exception of Stony Creek where the contact is faulted (Figure 2.7).

Microfossil samples S31/f802 and f505 (Fletcher Creek), and S31/f805 (Hunt Creek) from the De Filippi Mudstone near the Ram Creek contact contain early? Altonian mid to outer shelf faunas, while a thin (34m at Hunt Creek) Ram Creek Member is gradationally overlain by late Altonian Rotokohu Coal Measures. The Ram Creek/De Filippi Mudstone contact at these two sections is inferred to be disconformable, representing an abrupt change from early Altonian mid to outer shelf mudstone, to a thin sequence of late? Altonian shallow marine sandstone.

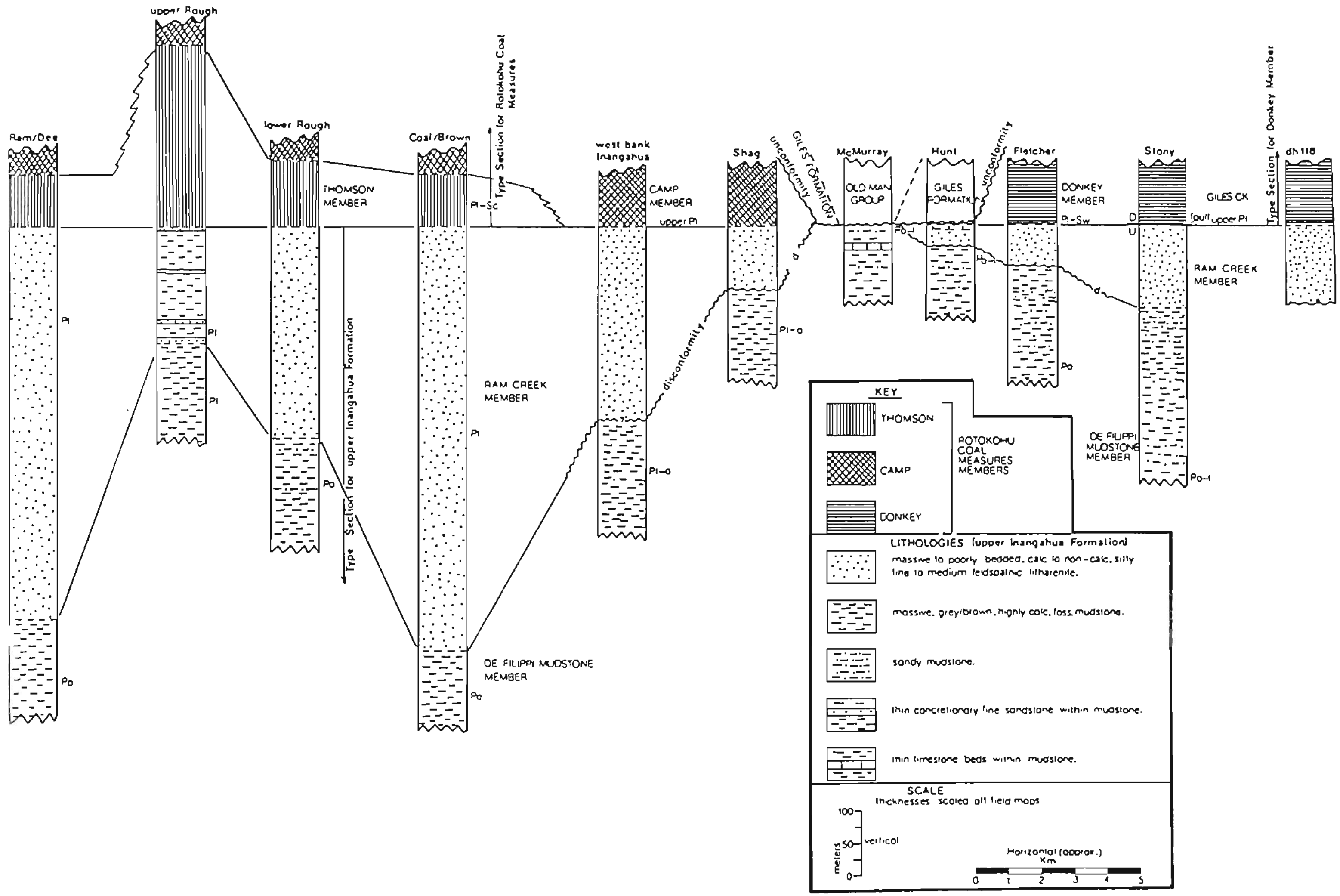


Figure 2.5: Proposed correlation of Ram Creek Member within the Inangahua Valley.

Figure 2.6: Mudstone dominated facies of the Ram Creek Member, upper Rough Creek, approximately 25m downstream from the base of the Rotokohu Coal Measures. Fine concretionary sandstone beds form resistant outcrops, but are generally subordinate to massive mudstone.

Figure 2.7: Fault contact between the Ram Creek and Donkey Members, Stony River. Fault plane has an apparent dip of 60° to the west, with the Ram Creek Member thrust over the Donkey Member. Hammer is approximately 25cm long.

2.3 ROTOKOHU COAL MEASURES (Nathan 1974)

Nathan (1974) introduced the term Rotokohu Coal Measures for what was interpreted to be a continuous sequence of late Altonian to Opoitian nonmarine sediments, comprised of "medium to coarse arkosic sandstone, with beds of greywacke conglomerate, carbonaceous mudstone, and scattered lensoid coal seams". These sediments were considered to be widespread within both the Inangahua and Grey Valleys (Wellman 1950, Nathan 1974, 1978a and b, Nathan and others 1986).

The Rotokohu Coal Measures are re-defined here as late Altonian to Waiauan, predominantly nonmarine, sandstone, quartzose greywacke conglomerate, carbonaceous mudstone and coal, outcropping within the Inangahua Valley. No Taranakian sediments are preserved in the Inangahua Valley. Nathan (1978c) recognised that sediments included with the Rotokohu Coal Measures in the Grey Valley are significantly younger (Opoitian to Waipipian, D.C. Mildenhall pers. comm.) than at the type section (predominantly Clifdenian, Mildenhall 1976), introducing the informal term " Moonlight Beds", but subsequently continued to relate them with the "type Rotokohu" in the Inangahua Valley (Nathan and others 1986). In this thesis the " Moonlight Beds" of the lower Grey Valley are related to the Giles Formation in the Inangahua Valley.

The base of the Rotokohu Coal Measures is defined as the first coal seam, or first dark grey/blue to grey/black, very carbonaceous mudstone with abundant well preserved plant remains, overlying the Ram Creek Member of the upper Inangahua Formation. The coal measures are subdivided into three new members, the Thomson, Camp and Donkey Members. Each is described in this section, but sedimentological aspects are discussed in more detail in Chapter 3.

2.3.1 Thomson Member Tm (new unit)

Name

The Thomson Member is named after Thomson Creek, a small tributary of the Buller River, draining the Welshman Pakihi region.

Type Locality

Coal Creek between L29 206205 and L29 210202 is proposed as the type section of the Thomson Member (Figure 2.8). Both the upper and lower contacts are well exposed (Figure 2.9 & 2.10), although the intervening stratigraphic sequence is poorly exposed.

Distribution and Thickness

The Thomson Member occurs only in the northern Inangahua Valley, outcropping intermittently from Coal Creek north-east to Ram Creek, and within the core of the Inangahua Syncline extending north into the Thomson Creek/Welshman Pakihi region.

Rapid thickness variations occur within this unit. The member is absent south of Inangahua Landing, with approximately 80m characterising the member throughout most of the northern Inangahua Valley. A maximum thickness of approximately 260m is observed in the upper Rough Creek area, and corresponds to a mudstone dominated facies variation within the underlying Ram Creek Member (Figures 2.5 and 2.6).

Description

The Thomson Member is always poorly exposed, with rarely more than 10m of continuous exposure. Two representative measured sections are provided showing the gradational upper and lower contacts of this unit (Figures 2.11 and 2.12). Burrowed, carbonaceous, fine to medium lithic feldsarenites containing large lined burrows, and bioturbated dark grey/blue to grey, carbonaceous sandy siltstones, are diagnostic of the Thomson Member. These bioturbated sandstones and siltstones varying in thickness from approximately 1m, up to an observed maximum of 9.5m. Additional lithologies interbedded with these bioturbated units include:

a) Thin (<1.5m), marginal marine? fossiliferous, carbonaceous mudstone, occurring locally at Rough, Camp and Thomson Creeks,
b) Frequent, thin (<1.5m), carbonaceous mudstones, commonly with abundant well preserved plant remains,
c) Thin (1-2m), carbonaceous sandstones, (commonly cross-bedded, or ripple laminated), and

COAL CREEK: SUMMARY COLUMN

GRID REFERENCES: (metric) Base 206 easting 204 northing NZMS 260 SHEET: L29 1979 map date : Top 239 easting 179 northing NZMS 260 SHEET: L30 1983 map date

METHOD OF MEASUREMENT: Scaled off final map & cross section

DATE OF MEASUREMENT: 25 & 26 of March 1985

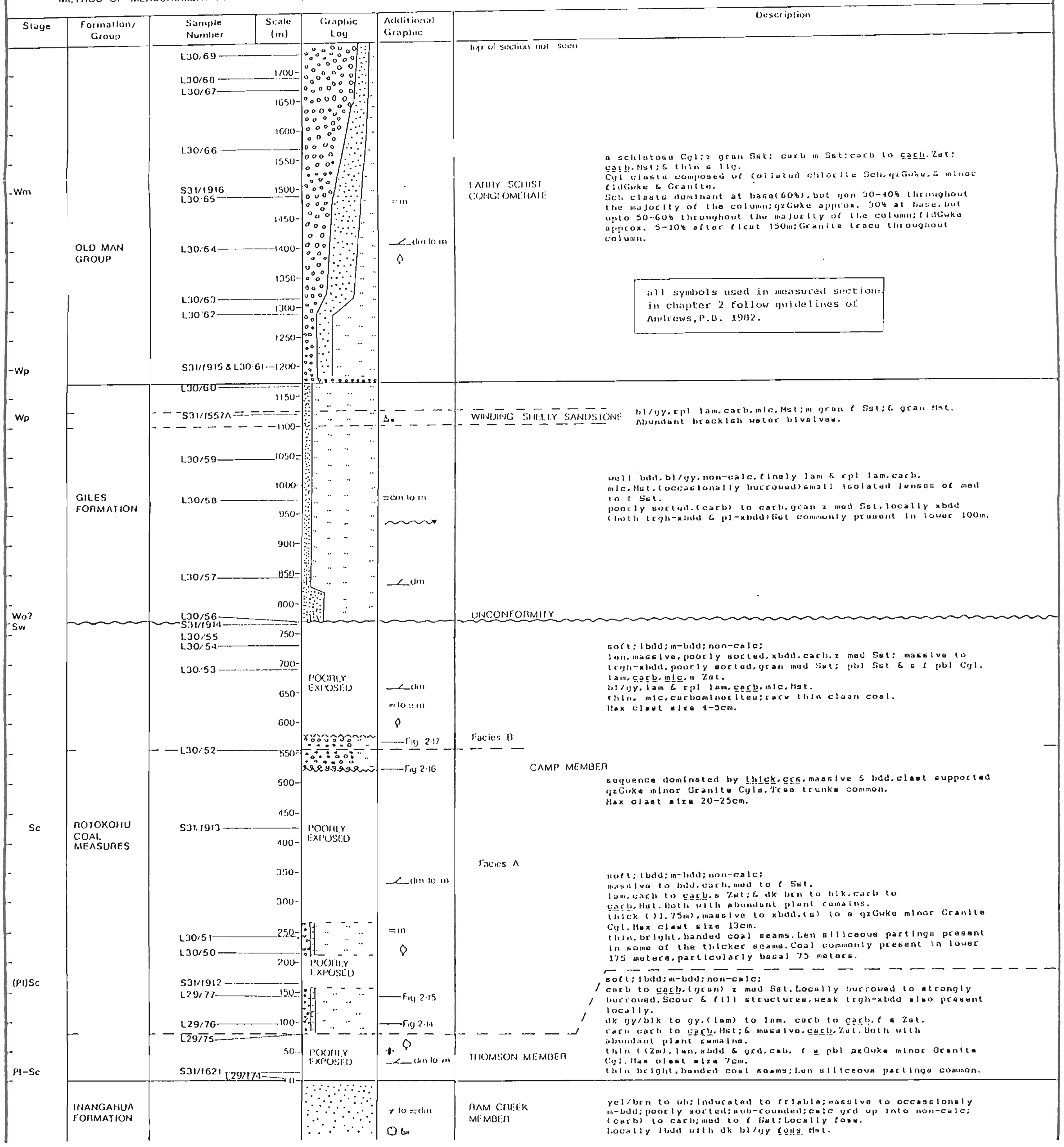


Figure 2.9: Gradational contact between Ram Creek Member (Inangahua Formation) and Thomson Member (Rotokohu Coal Measures) at Coal Creek. The thin coal seam marks the base of the coal measures (Hammer for scale).

Figure 2.10: Gradational contact between the Thomson and Camp Members at Coal Creek. The first thin coal seam above the hammer marks the contact. Pollen sample L29/75 to the right of the hammer contains marine dinoflagellates.

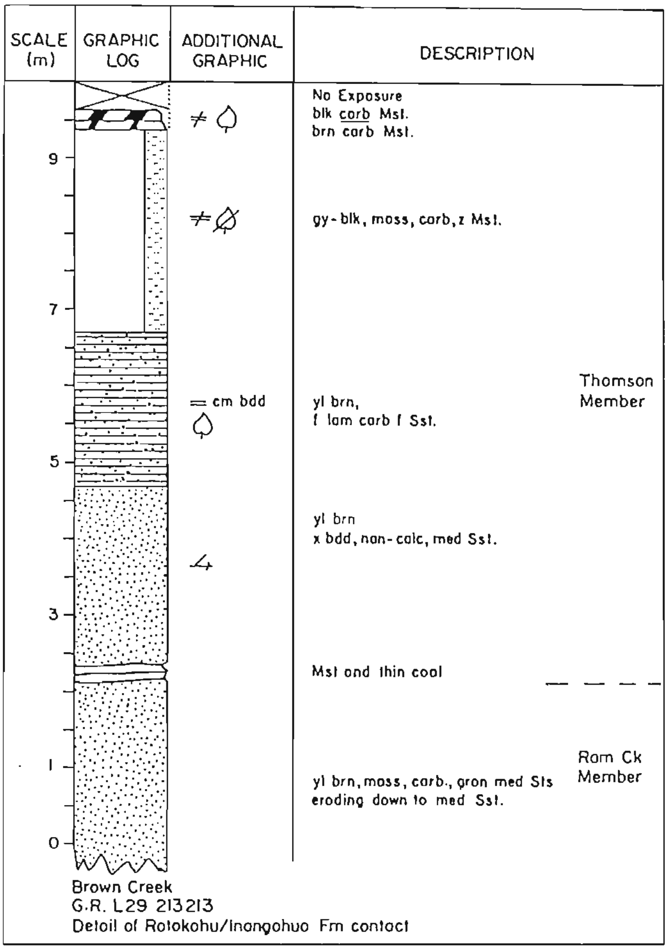


Figure 2.11: Measured section showing the gradational contact between Ram Creek Member (Inangahua Formation) and Thomson Member (Rotokohu Coal Measures) at Brown Creek.

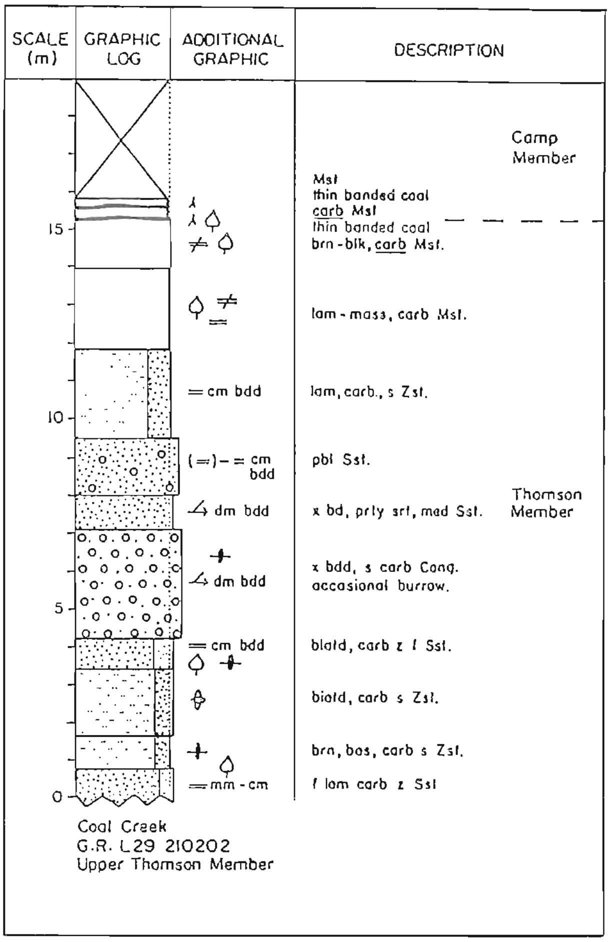


Figure 2.12: Measured section showing the gradational contact between the Thomson and Camp Members at Coal Creek.

Figure 2.13: Unconformable contact between the Camp Member (Rotokohu Coal Measures) and the Giles Formation. The contact is marked by the thin orange band just above the hammer.

d) Thin (commonly <1.5m, and frequently <2m) sandy, clast supported, fine pebbly conglomerates. Conglomerate clasts are generally comprised of fine (<7cm maximum), sub rounded Greenland Group (Nathan and others 1986) greywacke and argillite (approximately 75%, visual estimation), with minor granite and hornfels. Elongate, angular, rip-up clasts of carbonaceous mudstone and banded coal (generally 5-10cm long) are present within some conglomerate exposures.

e) Abunant thin (<1.5m), high sulphur (frequently >3% dry basis) coal seams occur in the Thomson Member, and are almost exclusively Type AB coal (Section 6.3).

Age

Only one sample from the Thomson Member has been dated at present (sample S31/f621 from Coal Creek, Figure 2.8). This sample was poor floristically, but dominated by subtropical Nothofagus "brassi" group pollen, and appeared to be Altonion to Waiauan in age (Mildenhall 1976). Samples from the overlying Camp Member indicate that the Thomson Member is no younger than Clifdenian at Coal Creek, while the underlying Ram Creek Member is dated as Altonian. On this basis a late Altonian to early Clifdenian age is adopted for the member.

Stratigraphic Relationships

The Thomson Member conformably and gradationally overlies the Ram Creek Member of the upper Inangahua Formation, and is in turn conformably and gradationally overlain by, and interfingures with, the Camp Member of the Rotokohu Coal Measures.

2.3.2 Camp Member Tc (new unit)

Name

The Camp Member is named after Camp Creek, a small tributary of Brown Creek.

Type Locality

Coal Creek from L29 210202 to L30 231189 is proposed as the type section of the Camp Member (Figure 2.8). Both upper and lower contacts are well exposed (Figure 2.10 and 2.13), although the intervening unit-stratotype is poorly exposed.

Distribution and Thickness

The Camp Member outcrops in the northern Inangahua Valley, from Shag Creek north-east to Brown Creek, and north into the Ram Creek area. Small erosional outliers occur in the core of the Inangahua Syncline in the Camp, Donnybrook and Thomson Creek areas.

The preserved thickness of the unit varies from a maximum of approximately 1,000m in the Gorgy Creek area; with the member locally eroded from the McMurray Creek area, and possible eroded from the eastern side of the Inangahua River.

Description

The Camp Member is always poorly exposed. Bioturbated sandstones containing large , lined burrows do not occur within the Camp Member. Typical lithologies of the Camp Member comprise:

a) Alternating sequences of carbonaceous mudstone and siltstone, commonly with well preserved plant remains, up to 25m thick; interbedded with thin (0.25 to 2m) carbonaceous, generally cross-bedded to ripple laminated, fine to medium lithic feldsarenites.

b) Thick (>2m) conglomerates are characteristic of the Camp Member, occurring as:
   i) 2-3m beds of massive, occasionally clast supported conglomerate interbedded with thick sequences of fine grained sediment (i.e. siltstones/mudstones) [Figures 2.14 and 2.15], and
   ii) thick (up to 25m) exposures of crudely bedded, clast supported conglomerate, interbedded with minor sandstone and mudstone (Figures 2.16 and 2.17).

Conglomerate clasts are dominated by Greenland Group derived quartzose greywacke and argillite (approximately 75%; visual estimate), with minor granite and hornfels. Elongate, angular rip-up clasts of carbonaceous mudstone and coaly material (generally less than 8cm long), and large logs occasionally occur in the conglomerates. A distinct reduction in maximum clast size is observed in the vertical sequence exposed at the type section, and is tentatively mapped laterally into Brown Creek on the basis of a similar reduction in conglomerate clast size.

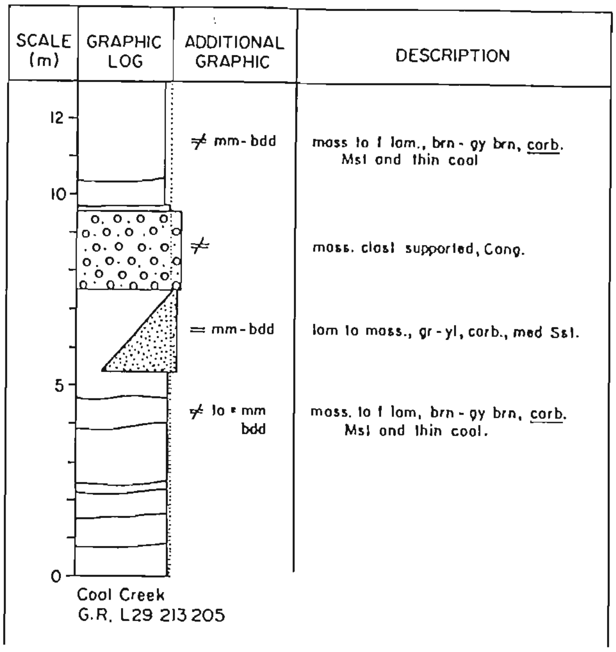


Figure 2.14: Measured section of the Camp Member from Coal Creek (see Figure 2.8 for approximate location).

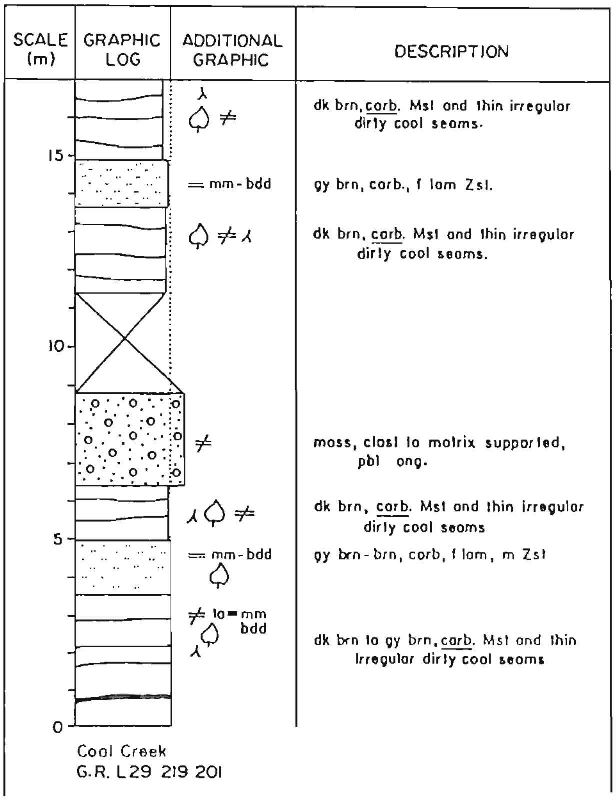


Figure 2.15: Measured section of the Camp Member from Coal Creek (see Figure 2.8 for approximate location).

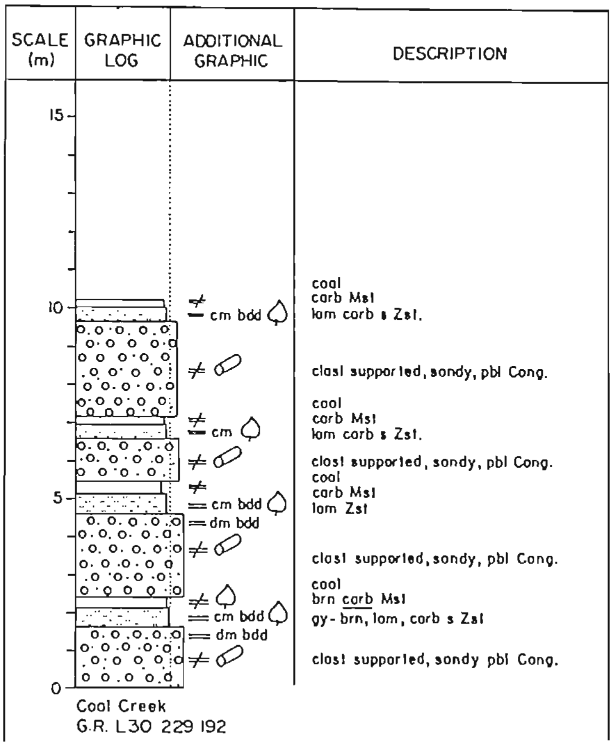


Figure 2.16: Measured section of the Camp Member from Coal Creek (see Figure 2.8 for approximate location).

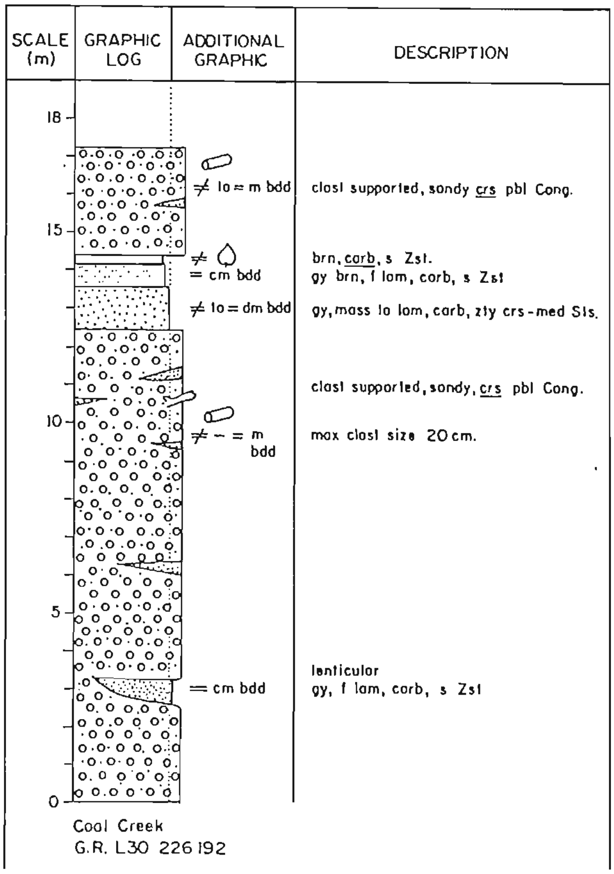


Figure 2.17: Measured section of the Camp Member from Coal Creek (see Figure 2.8 for approximate location).

North of Inangahua Landing coal seams within the Camp Member are usually thin (<1.5m), low sulphur (<2% dry basis), and consist of coal Types C, Cd and Co (Section 6.3). South of Inangahua Landing low sulphur Type AB coal occurs in the member, and thicker seams are developed (up to 7m).

Age

Palynological samples from the Camp Member indicate a late Altonian age for the base of the unit south of Inangahua Landing, and a late Altonian to Clifdenian age north of Inangahua Landing (Mildenhall 1976). A degree of diachroneity is suggested by these dates, with the Camp Member south of Inangahua Landing possibly the same age as the Thomson Member in the north. More dating is required over a wider area to determine the degree of diachroneity present in the base of the Camp Member, and in the Thomson Member.

The top of the Camp Member at Coal Creek is probably Waiauan (Mildenhall pers. comm.), hence a late Altonian to Waiauan age is adopted for the unit.

Stratigraphic Relationships

North of Inangahua Landing the Camp Member conformably and gradationally overlies the Thomson Member. South of Inangahua Landing the unit conformably and gradationally overlies the Ram Creek Member of the upper Inangahua Formation. Thus both palynology and physical stratigraphy suggest that the lower part of the member in the south is equivalent to the Thomson Member in the north.

The Camp Member is unconformably overlain by the Giles Formation at all sections.

2.3.3 Donkey Member Td (new unit)

Name

The Donkey Member is named after Donkey Creek, a small tributary of the Inangahua River south of Giles Creek.

Type Locality

No single section provides a complete representative sequence through the Donkey Member, and consequently a composite stratotype is proposed. The fully cored interval from 6 to 177.3m in drill hole 118 is proposed as the holostratotype for the member (Figure 2.18 and Appendix 12), while Fletcher

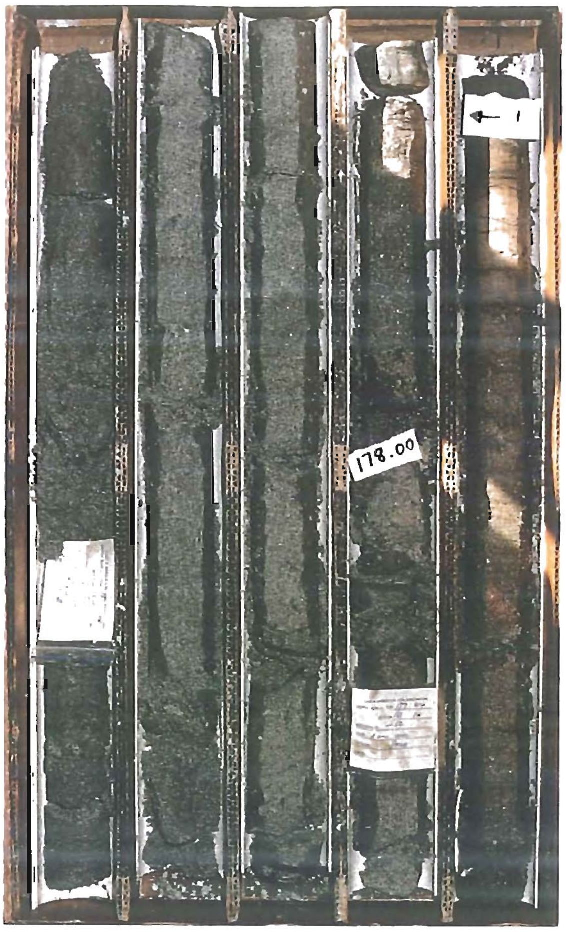


Figure 2.18: Gradational contact between the base of the Donkey Member, and the Ram Creek Member in DH 118. Small arrow marks the contact. Each section of core is approximately 0.60m (Top of section=T).

Figure 2.19: Unconformable contact between the Donkey Member and Giles Formation at Fletcher Creek. Silty, fine to medium sandstone of the Giles Formation overlying, thin very carbonaceous mudstone of the Donkey Member.

Creek, at L30 128124, is proposed as the parastratotype for the top 1.5m of the member (Figure 2.19). (DH 118 grid reference K30 100064, was drilled for Mines Division as part of the New Zealand Coal Resources Survey; core currently held by Landmark Resources, at Westport).

Distribution and Thickness

The Donkey Member crops out in the south-western Inangahua Valley, from Hunt Creek south to Giles Creek.

The preserved thickness of the unit, which was truncated prior to deposition of younger sediments, varies from 0m to an observed maximum of 180m in drill hole 118, up to a possible maximum of approximately 300m in the mid Giles Creek area.

Rapid thickness variations observed within the Donkey Member primarily reflect post-depositional, late Miocene to early Pliocene tectonics along an active basin margin, and are not directly related to the original depositional thickness of the unit.

Description

The Donkey Member is generally very poorly exposed, although locally well exposed in mine sections. Festoon cross-bedded, medium to coarse lithic feldsarenites are the dominant channel sediments within the Donkey Member. In contrast to the Camp Member, conglomerate is thin (<3m), fine (maximum clast <7cm), and rare, however clast lithologies are similar at Fletcher Creek (and appear to be similar in DH 118). Additional lithologies interbedded with cross-bedded sandstones in the Donkey Member include:

a) thick sequences (up to 13m) of ripple laminated sandstone,
b) massive, carbonaceous mudstone/siltstone, locally thick (>2m), but also commonly occuring as thin drapes (<0.5m), and
c) thick (>3m), low sulphur coal, commonly occurs at the base of the member, and locally occurs in the upper Donkey Member at Giles Creek.

A detailed 170m measured section from drill hole 118 is provided in Appendix 12, and is considered to represent the unit. Relatively fine grained lithologies (i.e. <granular sand) predominate, and a progressive coarsening upward trend is evident. This trend may be characteristic of the member at Giles Creek, although conglomerate is present in the lower Donkey Member at Fletcher Creek (Figure 3.31) near the presumed lateral gradation with the Camp Member.

Age

Recent palynological work indicates that the base of the Donkey Member at Giles Creek is late Altonian, with the upper part of the unit probably Waiauan (Mildenhall pers. comm.). Thus, a similar age is indicated for both the Donkey and Camp Members.

Stratigraphic Relationships

The Donkey Member conformably and gradationally overlies the Ram Creek Member of the upper Inangahua Formation, and is everywhere overlain in angular unconformity by the Giles Formation. Palynology (discussed previously) indicates that the Donkey Member is laterally equivalent to the Camp and Thomson Members of the northern Inangahua Valley, while physical stratigraphy suggests that the lateral gradation between the Camp and Donkey Members occured in the McMurray Creek area.

2.4 GILES FORMATION Gf (new formation)

The Giles Formation is a new formation previously unrecognised within the Grey/Inangahua Valleys. Formal lithostratigraphic subdivision of this unit must await remapping of the area from Larry River south to Ahaura. In this study an informal subdivision is proposed, into one member, and four lithofacies. A possible depositional environment is provided for the formation in this section to complement the stratigraphic subdivision proposed. A detailed paleoenvironmental analysis of the formation is outside the objectives of this thesis, and is not attempted.

Name

The Giles Formation is named after Giles Creek, a tributary of the Inangahua River.

Distribution and Thickness

The Giles Formation outcrops on the eastern and western margins of the central Inangahua Valley, and is correlated with similar aged sediments identified by Nathan (1978c) in the Moonlight Creek area.

Within the study area, the Giles Formation varies in thickness from a maximum of approximately 400m at Coal Creek (Figure 2.8), and is locally absent from the McMurray Creek area.

Description

The Giles Formation consists predominantly of blue/grey, non-calcareous, slightly carbonaceous micaceous siltstone, and silty non-calcareous, slightly carbonaceous sandstone. Conglomerate, thin high sulphur coal seams, and massive very carbonaceous mudstone with abundant plant remains occur locally. A thin fossiliferous horizon, the Winding Shelly Sandstone, is present in the upper Giles Formation at most sections.

Age

Recent palynological work on samples from Giles and Coal Creeks indicates that the base of the Giles Formation is Opoitian, and the bulk of the unit Waipipian in age (Mildenhall pers. comm.).

Stratigraphic Relationships

The Giles Formation unconformably overlies older Tertiary sediments, and pre-Tertiary basement, within the Inangahua Valley. North of St Helena Creek the formation unconformably overlies the Camp Member of the Rotokohu Coal Measures. From Inangahua Landing south-west to Giles Creek the Giles Formation unconformably overlies Rotokohu Coal Measures and older Tertiary sediments in a complex angular relationship. Suggate (1957) has shown that this sub-Wanganui unconformity truncates progressively older Tertiary sediments and pre-Tertiary basement on the eastern margin of the Reefton Subdivision, from Larry River south towards Ahaura.

2.4.1 Winding Shelly Sandstone Ws (Nathan 1974)

Nathan formally defined the Winding Shelly Sandstone as a thin band of Waipipian sandstone and mudstone containing abundant shallow marine macrofossils, outcropping in the south-western and central Inangahua Valley. Nathan considered the Winding Shelly Sandstone to be a separate formation from the Rotokohu Coal Measures, and assigned the unit to the Blue Bottom Group. Herein the Winding Shelly Sandstone is assigned member status within the Giles Formation, but all other aspects of Nathans definition are retained.

Distribution and Thickness

The Winding Shelly Sandstone is a thin, locally discontinuous unit outcropping from near Sleeper Creek (south of Giles Creek, P White pers. comm.), north to Inangahua Landing, and then north-east into Brown Creek.

The unit varies in thickness from a maximum of 29m at Hunt Creek (Figure 2.20), and is locally absent from the mid Giles, Dunphy, and Rough Creek areas.

Description

The Winding Shelly Sandstone consists of ripple laminated and massive siltstones, massive muddy medium to granular sandstone, and massive sandy mudstone. The characteristic feature of the unit is the presence of 2-6 thin (<0.5m), highly fossiliferous beds containing abundant shallow water macro-fossils, generally within a very poorly sorted granular, muddy, medium to fine sandstone (Figures 2.21 and 2.22).

The well exposed Hunt Creek section (Figures 2.20 and 2.21), and the type section (as defined by Nathan 1974 at Coal Creek, Figures 2.7 and 2.22) provide excellent exposure of this unit.

Age and Paleoecology

Macrofossil samples indicate a broad Opoitian to Waipipian age for this unit, while recent palynological dating of the Giles Formation at Coal Creek (Mildenhall pers. comm.) supports Nathan's (1974) interpretation of a Waipipian age for the unit.

None of the macrofossil collections from the Winding Shelly Sandstone (Appendix 3) indicate fully open marine conditions (A.G. Beu pers. comm.). A number of the taxa present are inferred to have lived only in large, shallow, sheltered, full-salinity bay environments. Sample S31/f557 from Coal Creek includes a number of estuarine taxa as well as

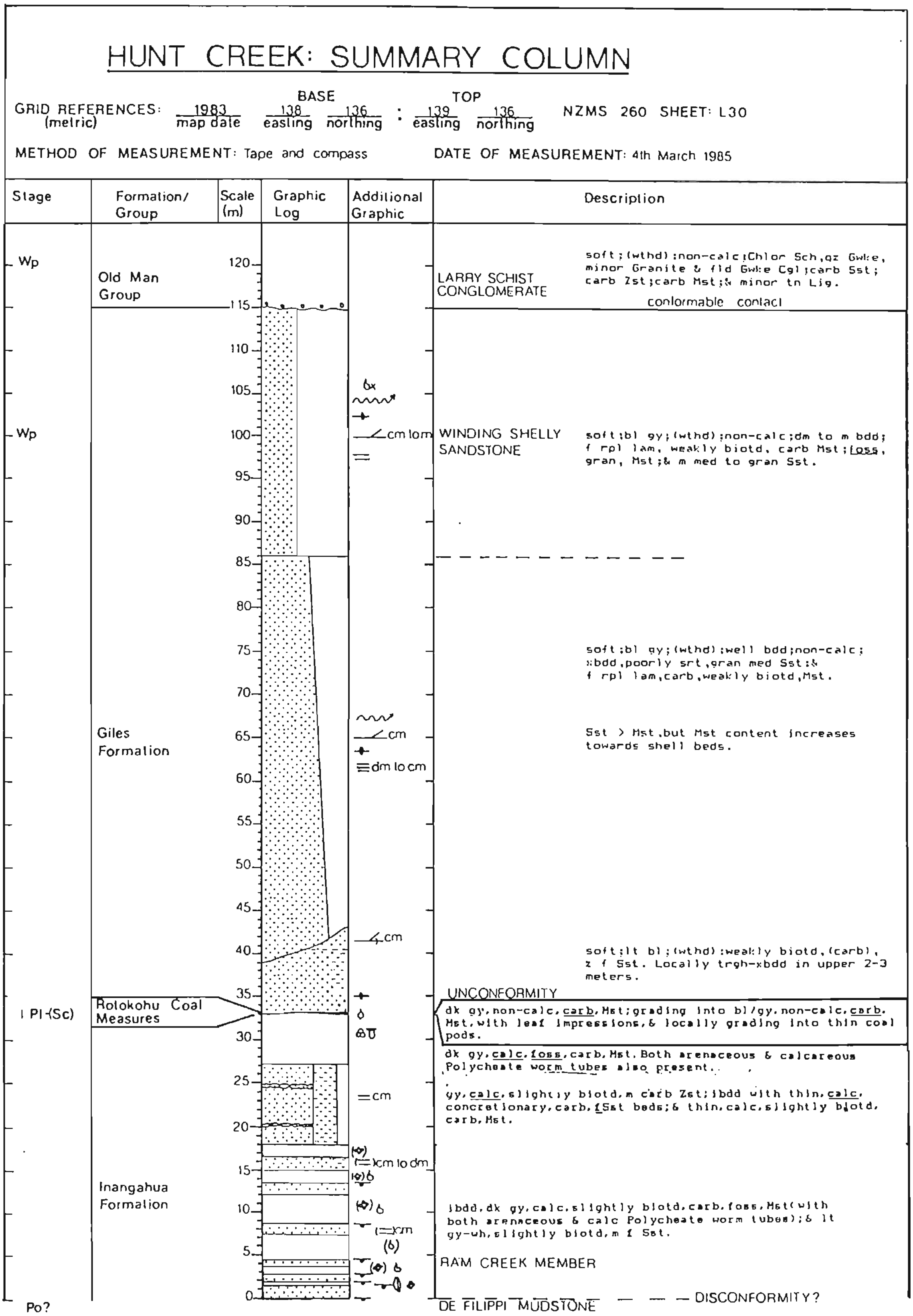


Figure 2.20: Measured section of Giles Formation at Hunt Creek.

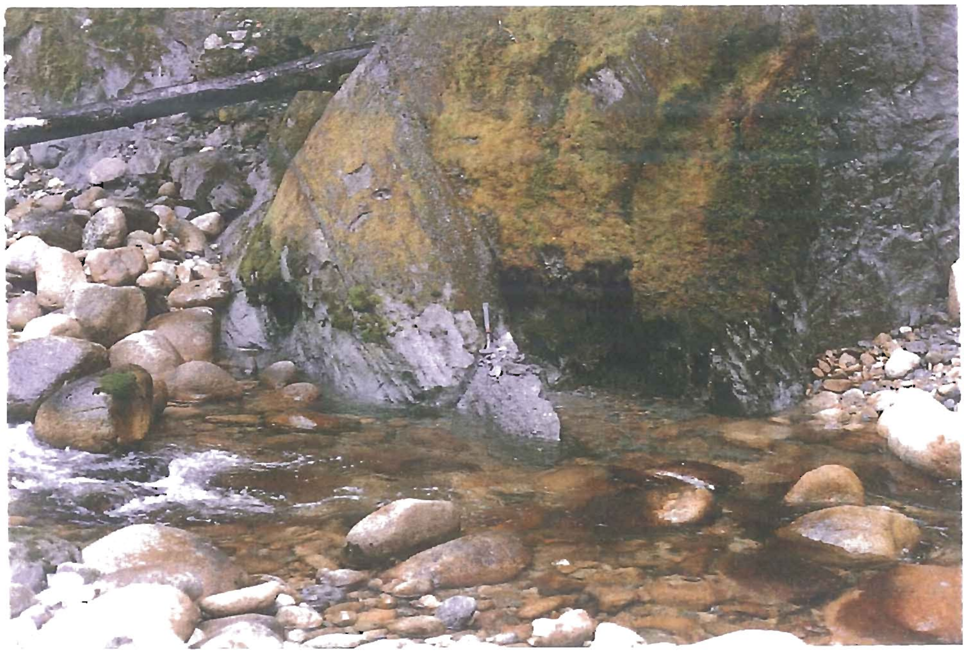


Figure 2.21: Winding Shelly Sandstone exposed at Hunt Creek. Hammer rests on one of the shell beds which characterise this unit.

Figure 2.22: Winding Shelly Sandstone exposed at Coal Creek. Thin shell bed horizon in right hand corner is interbedded with ripple laminated siltstone which is characteristic of the mudstone dominated lithofacies.

the characteristic sheltered bay assemblage. This fauna may contain a transported component, but is considered more likely to have been deposited within a shallow bay near the mouth of a major river (Beu pers. comm.).

Stratigraphic Relationships

The Winding Shelly Sandstone is always interbedded with the upper Giles Formation. The stratigraphic position of the unit appears to change towards McMurray Creek, becoming stratigraphically closer to the contact with the Old Man Group. This may imply that the unit is slightly diachronous towards the McMurray Creek area, or that the Giles Formation/Old Man Group contact is slightly diachronous. More dating is needed to clarify the nature of these contacts.

2.4.2 Lithofacies within the Giles Formation

Four poorly exposed lithofacies are recognised within the Giles Formation. Each is briefly defined here, and reference sections are provided where possible.

i) Mudstone Dominated Lithofacies Gf(m)

Distribution

The mudstone dominated lithofacies crops out in the north-eastern Inangahua Valley from Dunphy to Rough Creek, and locally in the south-west at Fletcher Creek.

Description

The poorly exposed Coal Creek section provides the best exposure of this lithofacies, and is designated as the reference section (Figure 2.8).

Blue/grey, non-calcareous, finely ripple laminated, slightly carbonaceous, micaceous siltstone is the dominant lithology of this lithofacies (Figure 2.23). Massive siltstone frequently occurs in all sections, but is generally subordinate to ripple laminated siltstone. Thin (<0.5m), generally lenticular, planar cross-bedded medium to granular sandstone beds occur in most outcrops, and are more common near the basal unconformity surface (up to approximately 30% of the unit). Massive, planar beds of granular to fine pebbly mudstone, and muddy granular/pebbly sandstone occur locally. Thin, dirty coal seams are observed to gradationally overlie massive mudstone at Brown Creek (Figure 2.24) and

Figure 2.23: Ripple laminated siltstone; mudstone dominated lithofacies, Giles Formation, Brown Creek.

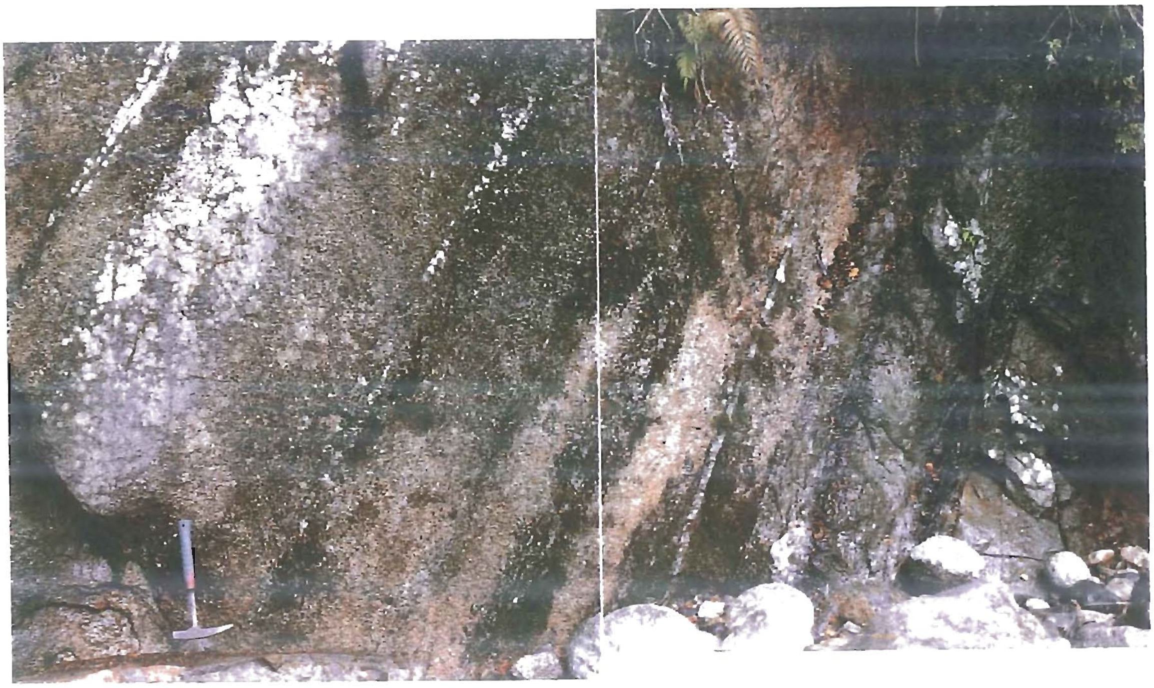


Figure 2.24: Thin, dirty coal seam, and planar beds of granular sandstone within the mudstone dominated lithofacies, Giles Formation, Brown Creek.

Dunphy Creek, and overlying finely laminated siltstone at Rough Creek.

ii) Sandstone Dominated Lithofacies Gf(s)

Distribution

The sandstone dominated lithofacies outcrops from Inangahua Landing south to Shag Creek, and at Hunt and Stony Creeks.

Description

The well exposed section at Hunt Creek provides a representative section of this lithofacies (Figure 2.20). The unit consists predominantly of non-calcareous, cross-bedded (locally bi-directionally), silty fine to medium sandstone (Figure 2.25), interbedded with minor (<15% of the unit), thin (<0.5m) beds of finely ripple laminated siltstone, commonly forming thin drapes on sandstone beds (Figures 2.26 and 2.27).

iii) Mixed Lithofacies Gf(x)

Distribution

This lithofacies occurs only locally at Giles Creek.

Description

A small section exposed in a road cutting at Giles Creek provides the best exposure of this lithofacies (Figure 2.28). The unit is characterised by thin, dirty, high sulphur (2 samples analysed by CRA contained 2.1 & 5.2% sulphur, db) coal seams (ash determination based on limited proximate analyses [Appendix 8], and hand specimen estimation), interbedded with massive and cross-bedded medium sandstone, finely ripple laminated siltstone, and massive carbonaceous mudstone, with abundant plant fragments. The mixed lithofacies is dated as Waipipian (Mildenhall pers. comm.).

iv) St Helena lithofacies Gf(t)

Distribution

The St Helena lithofacies has so far been observed only at St Helena Creek, the south-eastern boundary of the study area, where it constitutes all of the Giles Formation.

Description

The St Helena lithofacies is extremely poorly exposed, hence no measured section is provided as a reference. The sediments that are exposed comprise medium lithic feldsare-

Figure 2.25: Bi-directional cross-bedded sandstone; sandstone dominated lithofacies, Stony River. Small mudstone rip-up clasts and pyrite concretions are also present.

Figure 2.26: Thick bed of ripple laminated siltstone, overlain by trough cross-bedded sandstone; sandstone dominated lithofacies, Stony River. Small pebbles within the sandstone (upper left corner) are predominantly granitic.

Figure 2.27: Mudstone drapes on dune bedforms within the sandstone dominated lithofacies at Stony River.

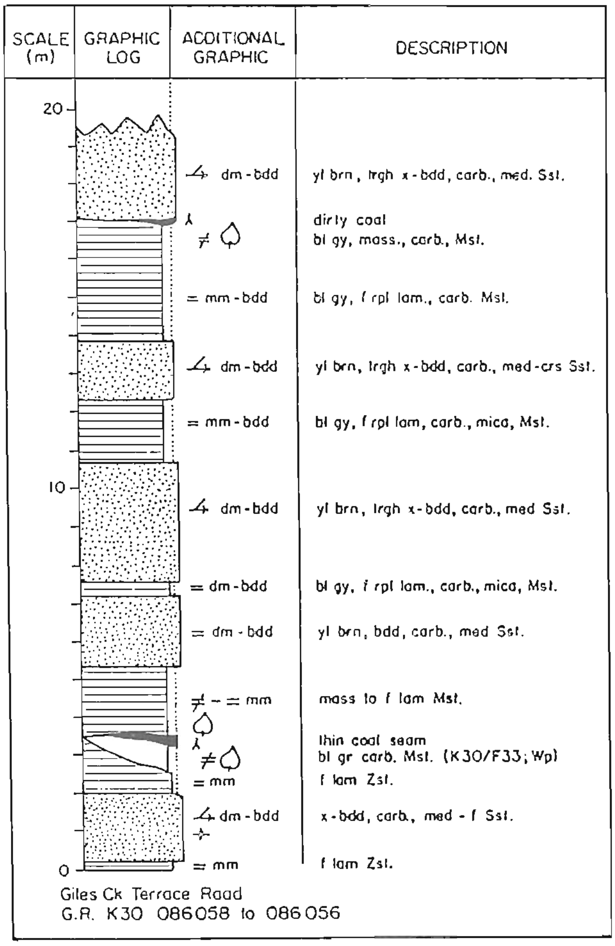


Figure 2.28: Measured section of mixed lithofacies at Giles Creek.

Figure 2.29: Mixed lithofacies, Giles Formation, Giles Creek containing a thin, lenticular coal seam (sample 11816).

nite, granitic cobble conglomerate, sandy carbonaceous mudstone with calcareous polychaete worm tubes, and calcareous, concretionary fine sandstone.

The St Helena lithofacies unconformably overlies the Whitecliffs Formation, and is conformably overlain by the Larry Schist conglomerate of the Old Man Group. The unit rapidly grades into the mudstone dominated lithofacies north of St Helena Creek.

2.4.3 Depositional Environment of the Giles Formation

The Giles Formation is thought to represent facies of a shallow, sheltered bay environment, grading laterally southeast into a locally derived (predominantly granitic source), nonmarine alluvial plain in the Reefton/Ahaura area.

The presence of marine dinoflagellates (Mildenhall pers. comm.), the shallow marine Winding Shelly Sandstone, and the characteristic finely ripple laminated and massive siltstone within the mudstone dominated lithofacies, are consistent with deposition in a large, shallow marine, mud shoreface. Similar features to those outlined above have been described by Rine and Ginsburg (1985) from recent mud dominated sediments of the Suriname coast.

The presence of thin coal seams with fine root horizons, gradationally overlying ripple laminated and massive siltstones, suggests a very shallow marine environment, with occasional periods of nonmarine deposition. Fine pebble and granular mudstone beds within the mudstone dominated lithofacies are interpreted to represent storm generated sheet-flood events, introduced from an adjacent major river system, and is consistent with the paleoecology suggested by macrofossils within the Winding Shelly Sandstone at Coal Creek.

The mudstone dominated lithofacies grades laterally from Winding Creek, west to Inangahua Landing, into the sandstone dominant lithofacies. The sandstone dominant lithofacies is inferred to represent sandstone deposition by migrating dune bedforms within the sheltered bay environment.

The mixed lithofacies and the St Helena lithofacies are interpreted as the transition from dominantly shallow marine sediments of the northen Inangahua Valley, into the nonmarine sediments of the Reefton/Ahaura areas.

2.5 OLD MAN GROUP (Nathan 1974)

Nathan (1974, p437) formally defined the Old Man Group as Waipipian to lower Nukumaruan "nonmarine conglomerate and sandstone, locally interbedded with minor peat and glacial beds." The abrupt incoming of allochthonous Haast Schist derived conglomerate defines the base of the Old Man Group within the Inangahua Valley.

Nathan recognised two formations within the Old Man Group in the Inangahua Valley i.e. the Larry Schist Conglomerate, and the Cronadun Conglomerate. Nathan's definitions of both formations are followed in this thesis.

The following brief discussion of the Old Man Group is included to complement the interpretation shown on the accompanying maps (maps 1,2,3, in the map pocket), and is not intended as a detailed stratigraphic discussion.

2.5.1 Larry Schist Conglomerate Ol (Nathan 1974)

Distribution and Thickness

The Larry Schist Conglomerate occurs extensively within the central and southern Inangahua Valley, and in the northeast at Rough Creek adjacent to the Lyell Fault.

The thickness of the unit varies from a minimum of approximately 150-200m at Hunt/McMurray Creek, to a maximum of approximately 650-700m in the lower Giles Creek area.

Description

The formation consists dominantly of sub rounded schistose pebbly conglomerates and blue/grey carbonaceous sandstone, with minor carbonaceous siltstone, very carbonaceous mudstone, and occasional thin sandy lignite beds.

Schist clasts are composed of foliated chlorite schist derived from the Haast Schist Group (Nathan 1974). Coal Creek provides the best exposed sequence of Larry Schist Conglomerate (Figure 2.8). Schist clasts are dominant at the base (about 60% schist clasts), but generally constitute 30-40% of clasts throughout most of the section, where as Greenland Group derived greywacke and argillite clasts constitute approximately 50-60% of the clasts. Sparse granite clasts occur throughout. Torlesse derived feldspathic greywacke (Nathan and others, 1986) clasts are present in the upper part of the Larry Schist Conglomerate at Coal Creek (approximately 5-10%).

A subtle change in clast size occurs within the upper Larry Schist Conglomerate. At Coal Creek pollen locations L30/f68 and L30f/69 (Figure 2.8; possibly near the Wp/Wm boundary, Mildenhall pers. comm.) maximum clast size is approximately 16cm, with an average clast size of 4-7cm. Schistose clasts occur in the finer size fraction (i.e. <7cm), while feldspathic greywacke clasts commonly occur in the coarser size fraction (i.e. >7cm). At the base of the Larry Schist Conglomerate at Coal Creek schistose clasts are coarser, up to 10-12cm, and occur in all size ranges, while feldspathic greywacke clasts are not present.

This relationship between clast size and composition is also observed within the upper Larry Schist Conglomerate in the McMurray/Shag Creek area, the Stony River section, and the upper Giles Creek forestry road section.

Age

The Larry Schist Conglomerate is mostly Waipipian, with the upper part at Coal Creek possibly as young as Mangapanian (Mildenhall pers. comm.).

Stratigraphic Relationships

The Larry Schist Conglomerate conformably overlies the Giles Formation throughout the southern Inangahua Valley. The only exception is at McMurray Creek, where the Larry Schist Conglomerate unconformably overlies the lower Inangahua Formation (lower De Filippi Mudstone).

2.5.2 <u>Cronadun Conglomerate</u> Ol (Nathan 1974)

During this thesis the Cronadun Conglomerate was mapped only on the south-western edge of the Inangahua Valley, from McMurray Creek south to Giles Creek.

<u>Distribution and Thickness</u>

The Cronadun Conglomerate occurs within the southern Inangahua Valley, and is always poorly exposed.

Nathan (1974) estimated the formation to be approximately 150m thick.

<u>Description</u>

Thick (>3m) conglomerate beds dominated by sub rounded, coarse pebbles, cobbles and boulders of Torlesse derived feldspathic greywacke (Nathan and others 1986), interbedded with minor carbonaceous sandstone, carbonaceous mudstone and very rare lignite beds.

Fine schist pebbles are present in the lower Cronadun Conglomerate. Greenland Group quartzose greywacke and granite clasts are a minor component of the conglomerate clasts.

<u>Age</u>

The Cronadun Conglomerate ranges in age from Mangapanian to possibly early Nukumaruan (Mildenhall pers. comm.).

<u>Stratigraphic Relationships</u>

The Cronadun Conglomerate conformably and gradationally overlies the Larry Schist Conglomerate. "No younger lower Quaternary formations are present in the Inangahua Valley." (Nathan 1974).

CHAPTER THREE

SEDIMENTOLOGY

3.1 INTRODUCTION

In this chapter, the sedimentology of the Rotokohu Coal Measures is discussed using the lithofacies approach proposed by Miall (1977), incorporating refinements proposed by Miall (1978) and Rust (1978).

Beds of similar lithological character are grouped into lithofacies, the basic rock unit described in this section. A summary of lithofacies commonly recognised in fluvial environments is presented in Table 3.1. Each lithofacies recognised in the Rotokohu Coal Measures is described, selected measured sections are discussed in terms of their lithofacies associations, and depositional environments are then interpreted for each section. An integrated depositional model for the Rotokohu Coal Measures, based on all available data including stratigraphic relationships, sedimentology, coal petrology and geochemistry, is presented in Chapter 7 .

3.2 LITHOFACIES DESCRIPTIONS

3.2.1 Conglomerate Lithofacies

Clast size within each conglomerate lithofacies varies up to a maximum of 20cm, with quartzose "Greenland Group greywacke and argillite" clasts (Nathan and others 1986) dominating all exposures (approximately 75% of gravel clasts).

Facies Gm: massive or crudely bedded framework conglomerate (Miall 1977). This lithofacies comprises a clast-supported, fine sandy, fine to coarse pebble conglomerate. Clasts are sub rounded, and locally faintly imbricated. Elongate, angular clasts of carbonaceous mudstone, coalified clasts (generally <8cm long) and large logs occur in some exposures. The fine sand and silt matrix is inferred to have

Facies Code	Lithofacies	Sedimentary structures	Interpretation
Gms	massive, matrix supported gravel	none	debris flow deposits
Gm	massive or crudely bedded gravel	horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits
Gt	gravel, stratified	trough crossbeds	minor channel fills
Gp	gravel, stratified	planar crossbeds	linguoid bars or deltaic growths from older bar remnants
St	sand, medium to v. coarse, may be pebbly	solitary (theta) or grouped (pi) trough crossbeds	dunes (lower flow regime)
Sp	sand, medium to v. coarse, may be pebbly	solitary (alpha) or grouped (omikron) planar crossbeds	linguoid, transverse bars, sand waves (lower flow regime)
Sr	sand, very fine to coarse	ripple marks of all types	ripples (lower flow regime)
Sh	sand, very fine to very coarse, may be pebbly	horizontal lamination, parting or streaming lineation	planar bed flow (l. and u. flow regime)
Sl	sand, fine	low angle (<10°) crossbeds	scour fills, crevasse splays, antidunes
Se	erosional scours with intraclasts	crude crossbedding	scour fills
Ss	sand, fine to coarse, may be pebbly	broad, shallow scours including eta cross-stratification	scour fills
Sse, She, Spe	sand	analogous to *Ss, Sh, Sp*	eolian deposits
Fl	sand, silt, mud	fine lamination, very small ripples	overbank or waning flood deposits
Fsc	silt, mud	laminated to massive	backswamp deposits
Fcf	mud	massive, with freshwater molluscs	backswamp pond deposits
Fm	mud, silt	massive, desiccation cracks	overbank or drape deposits
Fr	silt, mud	rootlets	seatearth
C	coal, carbonaceous mud	plants, mud films	swamp deposits
P	carbonate	pedogenic features	soil

Table 3.1: Summary of the major lithofacies in alluvial depositional environments (from Miall 1978).

filtered into the interstices following deposition (Miall 1977). Lithofacies Gm occurs either as:

(1) lenses of thick (commonly 1.75-3m), massive, clast-supported conglomerate (Figure 3.1); or

(2) superimposed units of crudely horizontally-stratified, clast supported conglomerate. Each unit commonly has an erosive base, marked by a coarse lag deposit which fines upward, and is locally observed to fine laterally (Figure 3.2). Thin sandstone lenses (lithofacies Sh) are commonly associated with these superimposed units of lithofacies Gm.

Facies Gms: massive matrix supported conglomerate (Rust 1978). Lithofacies Gms comprises a dominantly massive, matrix-supported, very sandy, fine to coarse conglomerate. Horizontal bedding and imbrication were no where observed. Conglomerate clasts are sub rounded, and commonly "float" within a poorly sorted sandy matrix. The base of this lithofacies is usually non-erosive although locally it is observed to fill scours into fine mudstone/siltstone lithofacies (Figure 3.3).

Facies Gp: Planar (tabular) cross-bedded, framework conglomerate (Miall 1977). Lithofacies Gp comprises distinctly stratified, planar cross-bedded, sandy fine pebble conglomerate. Lithofacies Gp locally gradationally overlies lithofacies Gm, although generally this lithofacies is rare within the Rotokohu Coal Measures.

Facies Gt: trough cross-bedded, frame-work conglomerate (Miall 1977). Lithofacies Gt comprises distinctly stratified, trough cross-bedded, sandy, fine pebble conglomerate. These units generally form small, broad channel-fills, commonly observed in amalgamated relationships. Each channel has an erosive base overlain by a small lag deposit. This lithofacies is very rare within the Rotokohu Coal Measures.

3.2.2 Sandstone lithofacies

Sandstone lithofacies generally occur as either small lenses associated with conglomerate lithofacies, or as distinct beds (of varying thickness) interbedded with fine mudstones and siltstones. Sandstones are generally sub rounded

Figure 3.1: Massive to imbricated, predominantly clast supported conglomerate (lithofacies Gm), composed of sub-rounded clasts of Greenland Group greywacke and argillite, and minor coarse-grained granite. Locality=Coal Creek, GR. L30 266192.

Figure 3.2: Crudely bedded, clast supported conglomerate lithofacies Gm), with reactivation surface marked by coarse basal lag. Locality=Coal Creek, GR. L30 226192.

Figure 3.3: Predominantly clast supported conglomerate (lithofacies Gm), scoured into thick sequence of overbank siltstones and thin coal. These conglomeratic crevasse-splay deposits occasionally appear to be matrix supported. Locality=Coal Creek, L29 219201.

Figure 3.4: Festoon cross-bedded sandstone scoured into mudstone of poorly drained basal coal sequence, Mulligans Mine (Fletcher Creek). An abundance of fine coally material defines the individual forsets.

lithic feldsarenites, with dark mica flakes commonly observed in hand specimen.

Facies St: trough cross-bedded sandstone (Miall 1977). Lithofacies St can consist of solitary scoops, or as cosets of mutually cross-cutting troughs (festoon cross-bedding, henceforth designated by "f", i.e. Stf). Overall grain size varies from coarse to fine sandstone, with granular to fine pebbly sandstone present in some exposures. Carbonaceous material is frequently present, varying from small sand sized grains of coaly material (Figure 3.4), up to small twigs and branches. Set thickness is typically 10-20cm, with a general upward decrease in grain size within each set. The base of individual cosets is erosional, with major erosion surfaces defining individual channel deposits in thick festoon cross-bedded sequences (Figures 3.5 and 3.6).

Facies Sh: horizontally-bedded sandstone (Miall 1977). Lithofacies Sh comprises massive or horizontally laminated, moderately sorted, very fine to medium sandstone (Figure 3.7). When interbedded within other sandstone lithofacies, both the upper and lower contact are commonly gradational. Where interbedded as small sand wedges within conglomerate lithofacies, the gravels overlie erosive surfaces (Figure 3.8).

Facies Sr: ripple cross-laminated sandstone (Miall 1977). Lithofacies Sr comprises carbonaceous, medium to very fine sandstone, with distinctive ripple cross-laminations (Figures 3.9, 3.10). Ripple amplitudes are generally less than 5cm, and commonly less than 3cm. Fine rootlets, burrows and mudstone drapes commonly occur in ripple troughs in finely rippled sandstone, commonly producing simple flaser bedding, while coarsely rippled units are characterised by slightly coarser grain size (fine-medium), and very thin mudstone drapes.

Facies Smz: massive, silty sandstone. Lithofacies Smz comprises massive, poorly sorted, silty sandstone (Figure 3.7). Carbonaceous content is variable, ranging from sparse to abundant. Individual lenses of this unit are always less than 1.5m, generally lenticular, and commonly grade up from

Figure 3.5: Overview of festoon cross-bedded sandstone at Giles Creek Mine (see Figure 3.26).

Figure 3.6: Detail of festoon cross-bedding at Giles Creek. Lens cap overlies a major erosion surface within the cross-bedded sequence, defining the base of a new channel sequence.

Figure 3.7: Horizontally laminated sandstone (lithofacies Sh), grading up into massive carbonaceous to very carbonaceous, silty sandstone (lithofacies Smz), thin coal, and massive carbonaceous mudstone. Locality=Ram Creek, Gr. L29 286257.

Figure 3.8: Wedge of horizontally laminated sandstone (lithofacies Sh) within thick sequence of lithofacies Gm. Locality=Coal Creek, GR. L30 226192.

Figure 3.9: Ripple laminated sandstone (lithofacies Sr), interpreted as a proximal crevasse-splay deposit within the basal poorly drain coal sequence at Giles Creek Mine. (See measured section, Figure 3.26).

Figure 3.10: Finely ripple laminated sandstone (lithofacies Sr) from levee deposits at Giles Creek Mine. Fine burrows and rootlets are common (arrowed) in these deposits.

underlying sandstone of lithofacies Sh, or overlie an erosive contact with lithofacies Sr. The upper boundary is commonly, but not always gradational with either lithofacies Sr, or fine grained sandy siltstones and coal (lithofacies Fm and Cl/Cd).

3.2.3 Fine-grained Lithofacies

Fine grained sediments are volumetrically important within the Rotokohu Coal Measures.

Facies Fl: laminated mud (Miall 1977). Finely parallel to discontinuous wavy, laminated (millimetre to centimetre scale) mud (predominantly silt), with minor sandstone. These fine grained sediments are always carbonaceous, commonly highly carbonaceous. Fine burrows and rootlets may be abundant, whereas in other outcrops fine lamination is enhanced by the alignment of leaves/stems along the base of bedding planes. The thickness of this lithofacies varies from less than 0.10m up to 3-4m, and always gradational overlies, and is commonly overlain by other relatively fine grained lithofacies (Sh, Fm and Cd/l), although locally erosively overlain by lithofacies Sr, St, or Gm.

Facies Fm: massive mud (Miall 1977). Lithofacies Fm consists of dark-coloured, massive, carbonaceous mudstone. In this study lithofacies Fm is restricted to thick (>0.05m) mudstone deposits, locally up to 4-5m. Well preserved leaves/stems, large roots and rootlets are common within this lithofacies. Lithofacies Fm commonly gradationally overlies and is overlain by relatively fine grained lithofacies Sr, Sh, Smz and Fl, is frequently interbedded with coal seams , and locally erosively overlain by lithofacies Sr, St, and Gm.

Lithofacies C: coal. Two subscripts are used, to denote clean coal (Cl), and dirty coal (Cd). The distinction between these two coal types is subjective, based on gross outcrop appearance. However petrographic examination and limited ash analyses of selected samples indicates that macroscopic assessment of coal mineral matter content is reliable, with lithofacies Cd generally containing greater than 25% ash (db, from proximate analyses).

3.2.4 Burrowed and bioturbated lithofacies

Burrowed and bioturbated lithofacies are not discussed by Miall (1977, 1978) or Rust (1978), in their discussions of depositional models for fluvial systems. Such lithofacies are however, discussed by Douglas (1985) for Miocene deltaic coal bearing sediments of the Manuherikia Group in Central Otago. These lithofacies are characteristic of the Thomson Member of the Rotokohu Coal Measures, and are texturally extremely variable, ranging from pebbly sandstone to mud.

Lithofacies Bs: burrowed sandstone. Lithofacies Bs comprises burrowed, massive to laminated, carbonaceous, very fine to coarse sandstone. Sequences of this lithofacies are thick (commonly >1m and locally up to 9m), and of variable grain size, although fine to medium sandstone is most common. Lower contacts are commonly erosive, while upper contacts are always gradational into lithofacies Mft or Bz. Burrows are always large, distinctly lined, sub-cylindrical forms, commonly one of three distinctive types:

a) *Arenicolites* sp. (Figure 3.11), simple, distinctly lined, smooth-walled, vertical U-shaped burrows lacking spreiten, and with near symmetrical limbs.
b) *Ophiomorpha* sp. (Figure 3.12), cylindrical, straight, non-branching, generally vertical to steeply inclined, sand filled, distinctly lined burrows, with an exterior consisting of small nodules of dark, carbonaceous clay material.
c) *Thalassinoides* sp. distinctly lined, smooth walled, bifurcating burrows. Burrow thickness is not always constant, while vertical shafts are usually more abundant than horizontal shafts (*Thalassinoides* burrows are generally gradational with *Ophiomorpha* burrows, with the terminology used in this thesis following that of Howard and Frey 1984).

The burrows described above are commonly interpreted as dwelling, or feeding-dwelling structures of vermiform animals (Howard & Frey 1984, Frey and Pemberton 1984, Hallam and Swett 1966).

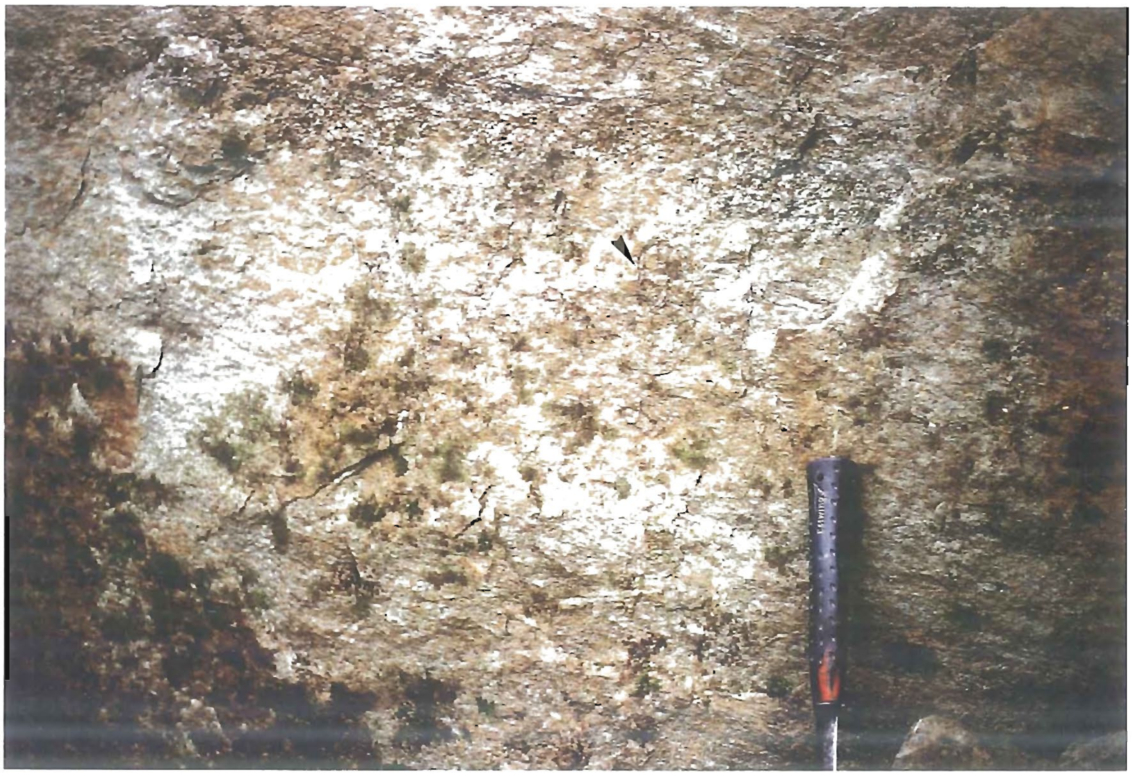


Figure 3.11: Arenicolites sp. burrow within burrowed, fine to medium sandstone (lithofacies Bs) at Coal Creek (see measured section Figure 3.14). Thalassinoides sp. burrows are also common at this locality.

Figure 3.12: Ophiomorpha sp. burrows within burrowed, fine to medium sandstone (lithofacies Bs). Locality=top of the Thomson Member, upper Rough Creek.

Lithofacies Mft: bioturbated, carbonaceous, muddy sandstone to sandy mudstone. This lithofacies comprises bioturbated, highly carbonaceous, muddy sandstone to sandy mudstone (Figure 3.13), generally 1 to 2m thick. General lebensspuren can not be identified in this lithofacies. Grain size is variable, but is commonly fine sandy mudstone. The lower contact of lithofacies Mft is frequently gradational from lithofacies Bs, while the upper contact is usually gradational with lithofacies Bz (defined below), or Cl, of coal Type AB (Section 6.3).

Lithofacies Bz: bioturbated, very carbonaceous mudstone. Lithofacies Bz comprises dark, bioturbated, highly carbonaceous mudstone, generally 0.5 to 2m thick, with most sedimentary structures destroyed by the bioturbation. These units commonly gradationally overlie lithofacies Mft, although abrupt contacts occur locally with lithofacies Bs, and are always gradationally overlain by lithofacies Cl, of coal Type AB (Section 6.3)

3.3 MEASURED SECTIONS

3.3.1 Thomson Member

The Thomson Member is always poorly exposed. Three measured sections are provided to illustrate characteristic features of the Member.

i) Coal Creek (Figure 3.14) and Dee Creek (Figure 3.15)

Coal and Dee Creek provide good, although small, exposures of the burrowed sandstones and siltstones (lithofacies Bs, Mft and Bz) which are characteristic of the Thomson Member.

In all exposures, vertical burrow components dominate horizontal components, lined burrows are the norm, and the diversity of burrow types is low. These features are typical morphological responses of organisms to a high to moderate energy, shifting substrate environment (Howard & Frey 1984), although water chemistry may also be a major influence on burrow morphology given the possible marginal marine environ-

Figure 3.13: Bioturbated, carbonaceous, muddy sandstone to sandy mudstone (lithofacies Mft), grading up into Type AB coal; lower Thomson Member, Rough Creek.

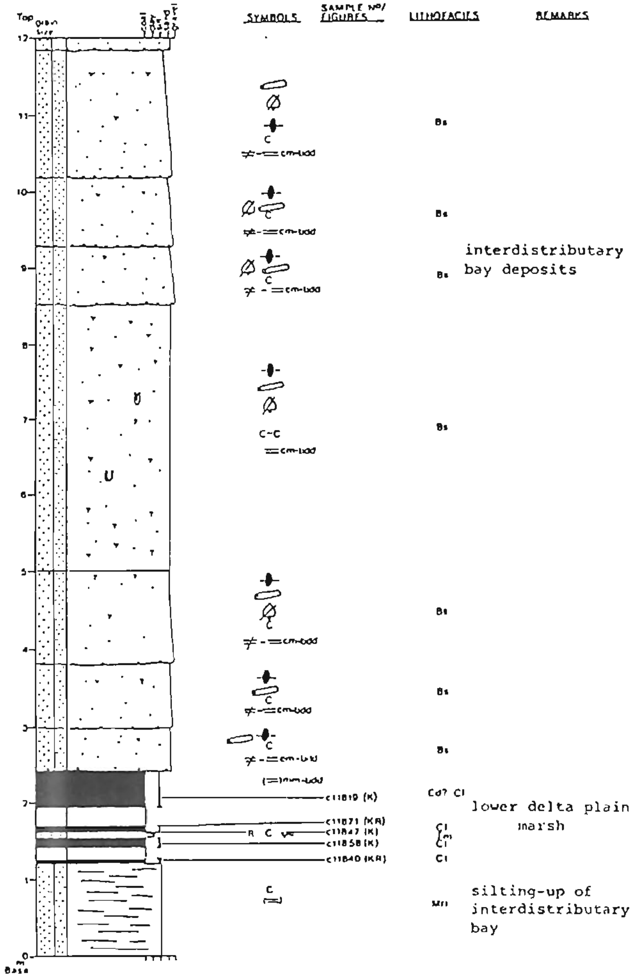


Figure 3.14: Measured section of bioturbated sandstones (lithofacies Bs and Bz) associated with thin Type AB coal, interpreted to represent interdistributary bay-fill sequences. Locality= Coal Creek GR. L29 208204.

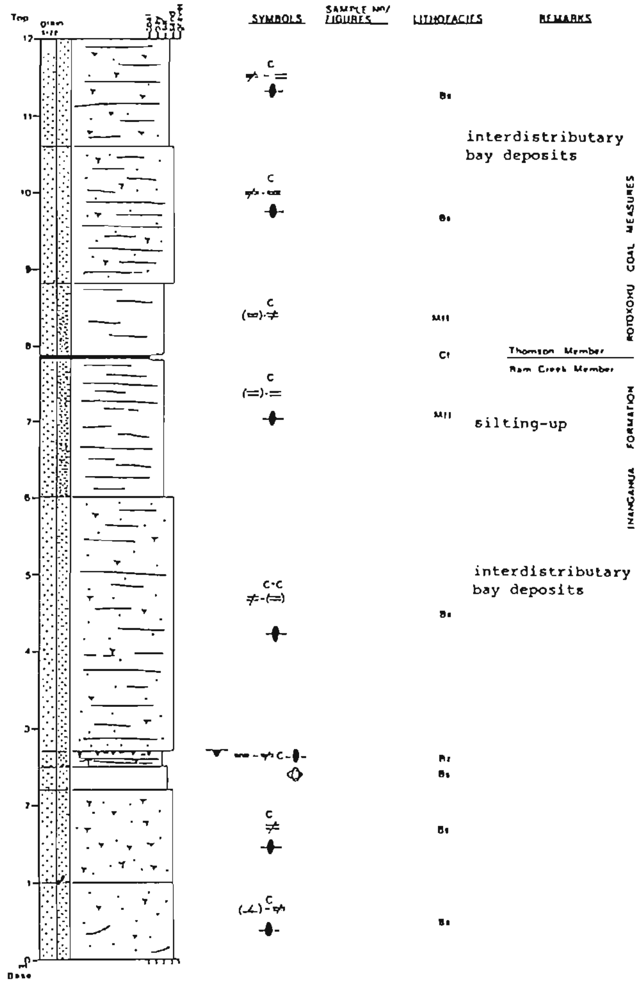


Figure 3.15: Measured section from Dee Creek showing bioturbated sandstones (lithofacies Bs and Bz).

ment of deposition (D.W.Lewis, pers. comm.)

Lithofacies Bs is generally discontinuously laminated to locally ripple laminated, moderately well sorted, fine to medium sandstone. Major erosive surfaces present in thick sequences of lithofacies Bs are abruptly overlain by very coarse to granular sandstone which rapid fines upward into medium sandstone (Figure 3.11).

The ichnofaunas present in lithofacies Bs (defined in Section 3.2) are commonly described from moderate to high energy, shallow to marginal marine depositional environments (Howard and Frey 1984, Archer and Maples 1984). The characteristic lithofacies sequence associated with burrowed sandstones in the Thomson Member is:

Bs -> Mft -> Bz -> Cl/Fm.

This lithofacies sequence is inferred to represent an interdistributary bay-fill sequence.

The term interdistributary bay is used as defined by Coleman et al.(1964) as "the areas between deltaic distributaries, irrespective of whether the bays are open to the sea or not." Lithofacies Bs (with its characteristic "marine" lebensspuren) is inferred to represent marine influenced, sandy bay-fill deposits, with lithofacies Mft and Bz (where present) representing the "silting-up" stage of the bay-fill history. The bay-fill sequences are gradationally overlain by a "lower delta plain" (Horne et al. 1978) marsh sequence consisting of lithofacies Cl and Fm.

The bay-fill sequences are inferred to represent cycles of frequent lobe abandonment and relocation of the nearest distributary channel. A similar mechanism of autocyclic lobe abandonment was proposed as the cause of the abrupt thickening of the Thomson Member in the upper Rough Creek area, and was interpreted (in Chapter 2) with the distribution of sandstone in the underlying Ram Creek Member as defining two major depositional lobes north of Inangahua Landing.

ii) Ram Creek (Figure 3.16)

Ram Creek provides a small but well exposed section showing the gradation from calcareous shallow marine sandstone and siltstone of the Ram Creek Member, into the Thomson Member of the Rotokohu Coal Measures (Figure 3.16).

A repetitive lithofacies sequence is observed in this section; each sequence consists of Stf -> Sh -> Smz -> Cl/Fm. These sequences are inferred to represent active distributary channel-fill composed of festoon cross-bedded, granular to fine sandstone (lithofacies Stf), followed by channel abandonment, producing fining-upward channel-fill sequences (lithofacies Sh -> Smz -> Cl/Fm).

The association of active and abandoned channel-fill, gradationally overlying shallow marine sandstones and siltstones, is characteristic of channel sedimentation in a lower delta plain environment where there is little tendency for lateral channel migration (Horne et al. 1978, Diessel 1984). The Ram Creek Section is comparable with fluvial-dominated lower delta plain sequences described in the literature (e.g. Figure 3.17).

Where present, lithofacies Sh is gradational with both lithofacies Stf and Smz (Figure 3.7), and is inferred to represent a waning in channel flow. Lithofacies Smz is interpreted as represent "silting-up" of abandoned channels, and grades up into delta marsh deposits (lithofacies Cl [coal Type AB] and Fm).

Coal seams from lower delta plain marsh deposits in the Thomson Member, are composed of marine-influenced Type AB coal (Section 6.3), frequently with high sulphur contents (>3% db). The high sulphur content, marine influenced coal type, and presence of marine dinoflagellates within all pollen samples collected from the Thomson Member at Coal Creek (Mildenhall pers. comm.), are consistent with the brackish "lower delta plain" depositional environment suggested by the lithostratigraphy.

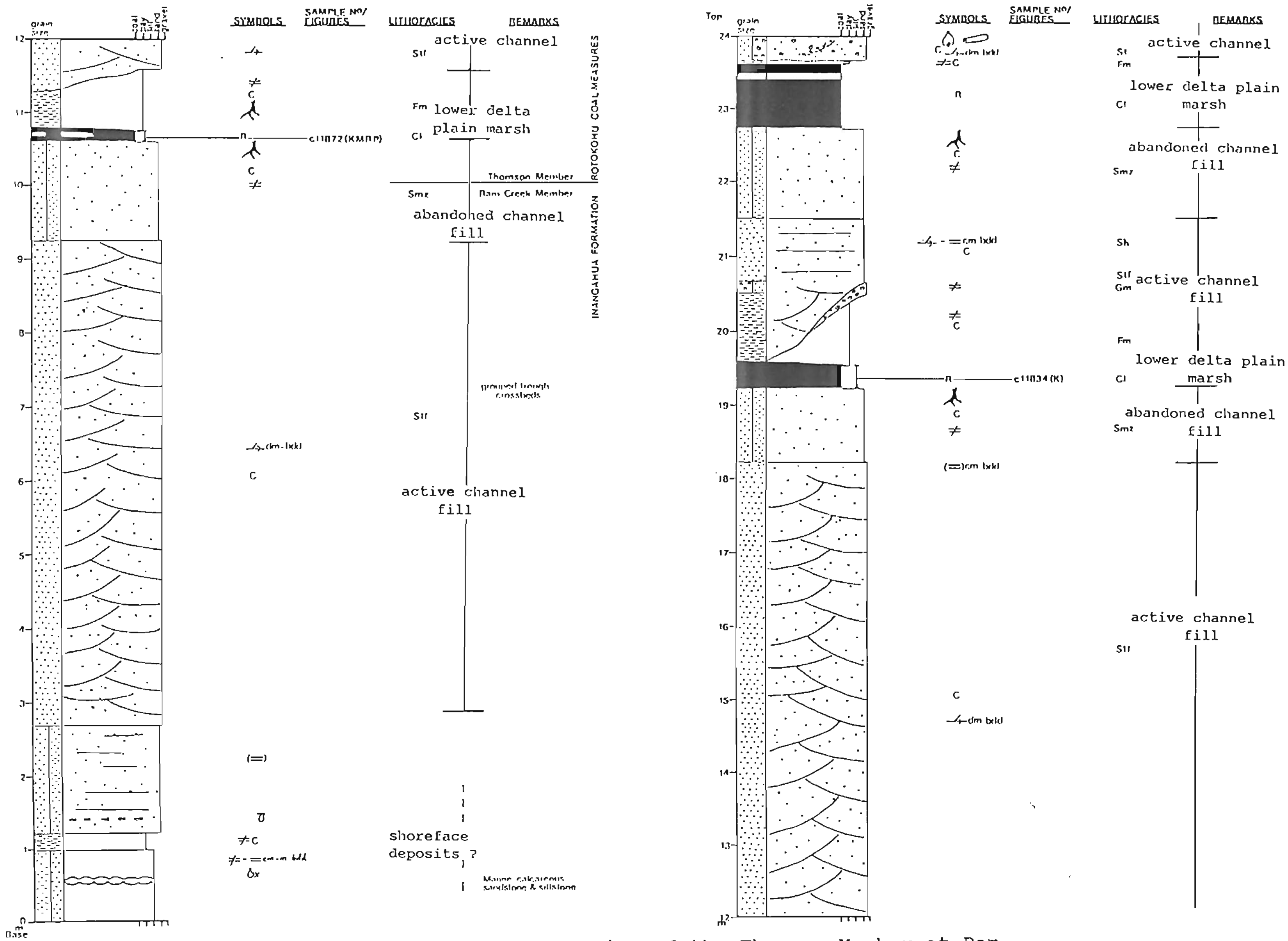
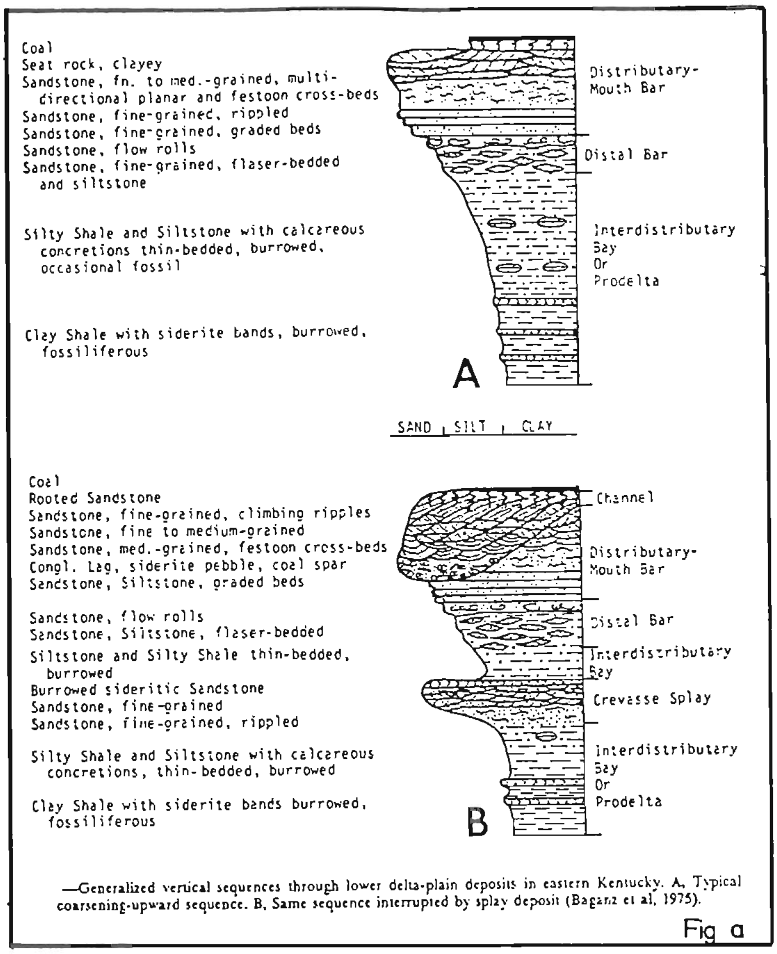


Figure 3.16: Measured section of the Thomson Member at Ram Creek.



—Generalized vertical sequences through lower delta-plain deposits in eastern Kentucky. A, Typical coarsening-upward sequence. B, Same sequence interrupted by splay deposit (Baganz et al, 1975).

Fig a

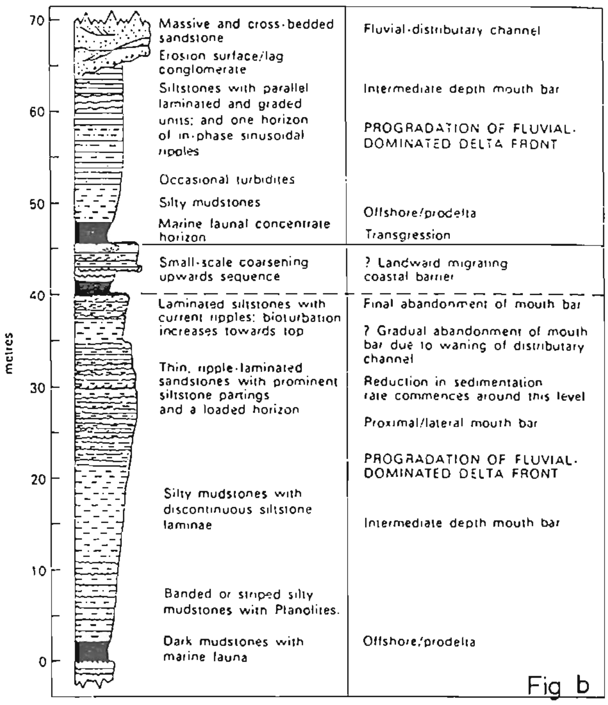


Fig b

Figure 3.17: Vertical sequences produced by fluvial dominated deltas: a) From Horne et al. 1978.
b) From Elliot, in Reading 1978.

3.3.2 Camp Member

Two lithofacies sequences are recognised within the Camp Member:

Sequence M: mudstone dominant

Sequence C: conglomerate dominant

i) Sequence C: Conglomerate-dominated lithofacies sequence

Two small measured sections are provided to demonstrate the characteristic vertical profile present within the conglomerate-dominated lithofacies sequence (Figures 3.18 and 3.19). Figure 3.18 provides a representative reference section for this lithofacies sequence. The sequence in this section comprises massive to crudely bedded, clast-supported conglomerate (lithofacies Gm and Gm/Gp), abruptly overlain by massive to horizontally-bedded sandstone (lithofacies Sh), gradationally overlain by thin, massive, carbonaceous mudstone and thin dirty coal (lithofacies Fm and Cd).

Lithofacies Gm and Gm/Gp are inferred to represent longitudinal bar deposits, similar to longitudinal bar deposits described by Miall (1977 and 1978), Rust (1978), and Douglas (1985). The commonly accepted model for the development of longitudinal bars is by aggradation of the coarser fractions of the bedload sediment in mid-channel areas, during the falling stage of flood episodes (Miall 1977, Rust 1978, Figure 3.20a).

Fine grained sandstones and mudstones overlying the coarse longitudinal bar sediments are interpreted as bar top sediments, formed by vertical accretion on relatively stable bar surfaces during intervals of reduced channel flow, and/or cannel abandonment (Cant 1978, Douglas 1985, Figure 3.20a). Bar top sediments within the Camp Member are characterised by a thin lithofacies sequence Sh -> Fm -> C -> Fm, overlying coarse sediments predominantly composed of lithofacies Gm.

The section shown in Figure 3.19 is interpreted as a sequence of bar top sediments (lithofacies Sh -> Fm -> Cl -> Fm -> Sh), overlain by a series of stacked longitudinal bar bedforms. The sandstone lenses observed are inferred to represent local sand wedges which developed on the edge of

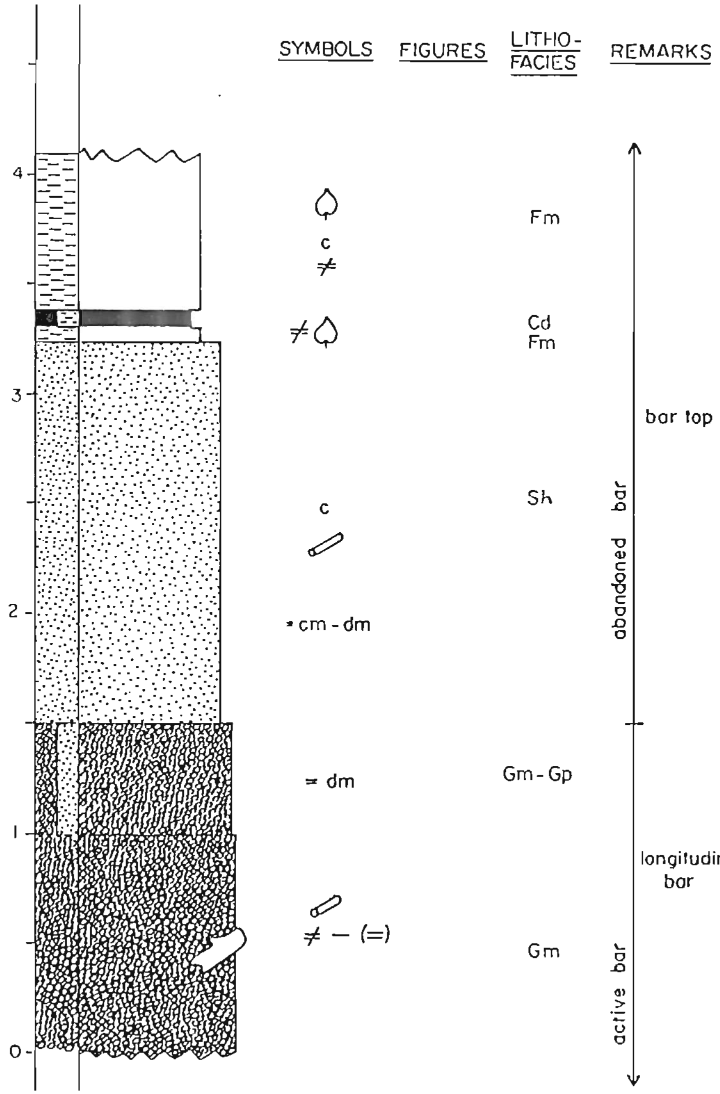
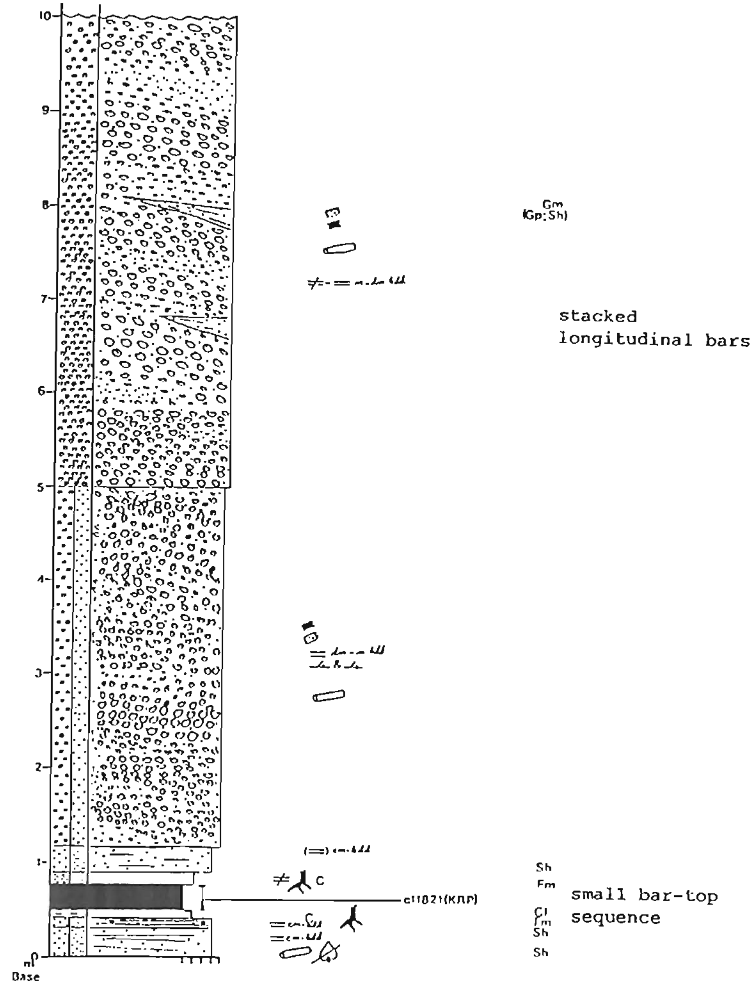


Figure 3.18: Measured section of conglomerate dominated lithofacies sequence (C), showing an individual longitudinal bar/bar top sequence. Locality=Brown Creek.

Figure 3.19: Measured section of longitudinal bar deposits overlying a thin bar top sequence from upper Brown Creek.



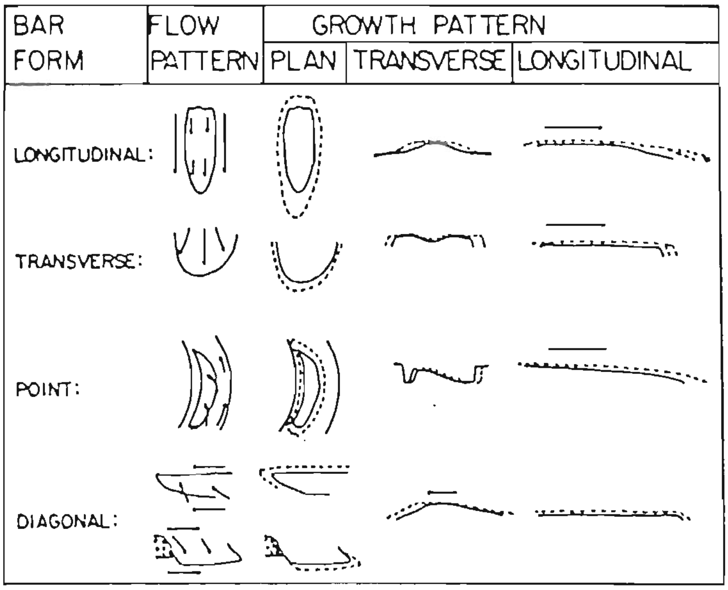
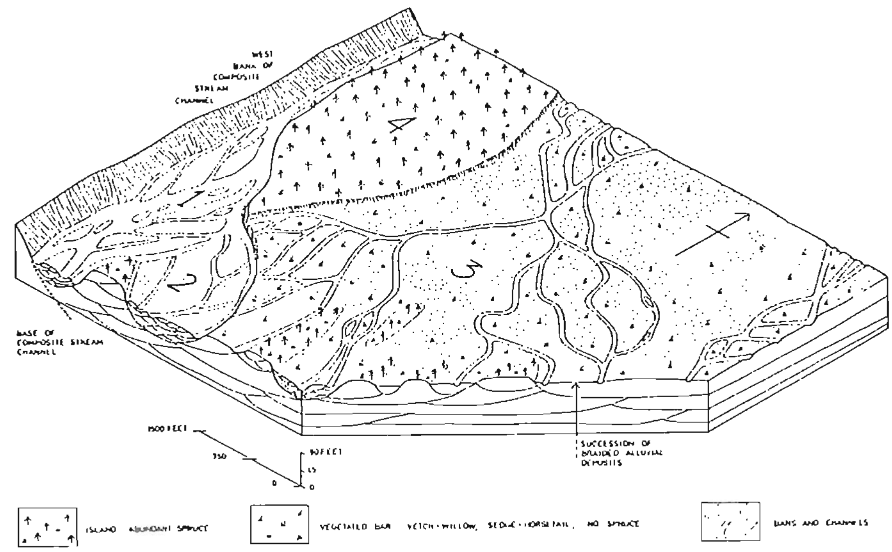


Fig. 3.20a i



Composite model of a braided river deposit. Fig. 3.20a ii

Figure 3.20a: i) Flow and growth patterns for typical bar forms (from Smith 1974). ii) Composite model of a braided river deposit showing the development of vegetated bar tops on abandoned bar surfaces (from Reineck and Singh 1980).

individual longitudinal bars, similar to those discussed by Rust (1978).

Sequences of complete bar units, similar to those of the Camp Member, were described by Douglas (1985) from the St Bathans Member of the Manuherika Group of Central Otago (Figure 3.20b), and the depositional environment was inferred to comprise braid channels.

The features observed in Figures 3.18 and 3.19 are used as a reference for other conglomerate exposures within the Camp Member. Figure 3.21 shows measured sections of two thick conglomerate exposures within the Camp Member. Both sections contain thick sequences of lithofacies Gm, interbedded with thin bar top sequences. Reactivation surfaces and sandstone wedges are commonly observed within the thick sequences of lithofacies Gm. Lithofacies Gms is not present in these conglomerate sections.

Facies models documented in the literature for braided river deposits provide analogies for the style of sedimentation observed within the conglomerate-dominated sequences of the Camp Member. Three principal vertical profile models for gravel-dominated braided river deposits are discussed by Miall (1978), and Rust (1978). The conglomerate-dominated sequences of the Camp Member have similarities to Miall's "Scott type" model (Figure 3.22), where "facies Gm" is dominant. The Scott model was proposed by Miall (1977 and 1978) for proximal, gravel-dominated, braided stream deposits, including those occurring on humid alluvial fans.

The major difference between the Scott model and conglomerate-dominated sequences within the Camp Member is the abundance of bar top sediments within the Camp Member. It is suggested that these bar top sediments resulted from frequent channel switching, within a broad alluvial plain, associated with high rates of sediment supply and subsidence. Frequent channel switching is a characteristic of braided streams developed on humid alluvial fans (Reineck and Singh, 1980), and is considered to be a good analogy for the paleoenvironment of the Camp member.

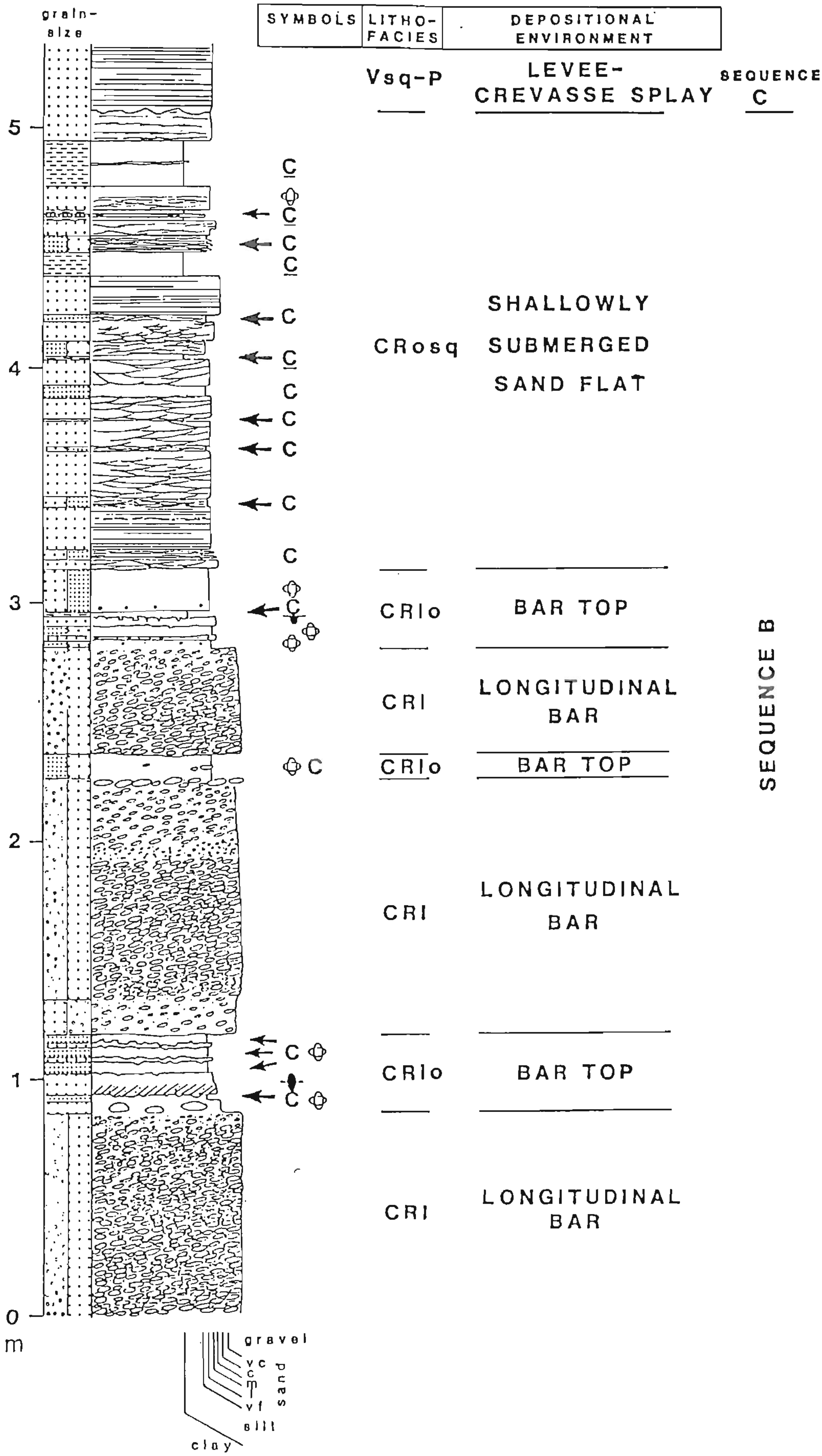


Figure 3.20b: Longitudinal bar sequences described by Douglas (1985) from the St. Bathans Member, Manuherikia Group, Central Otago.

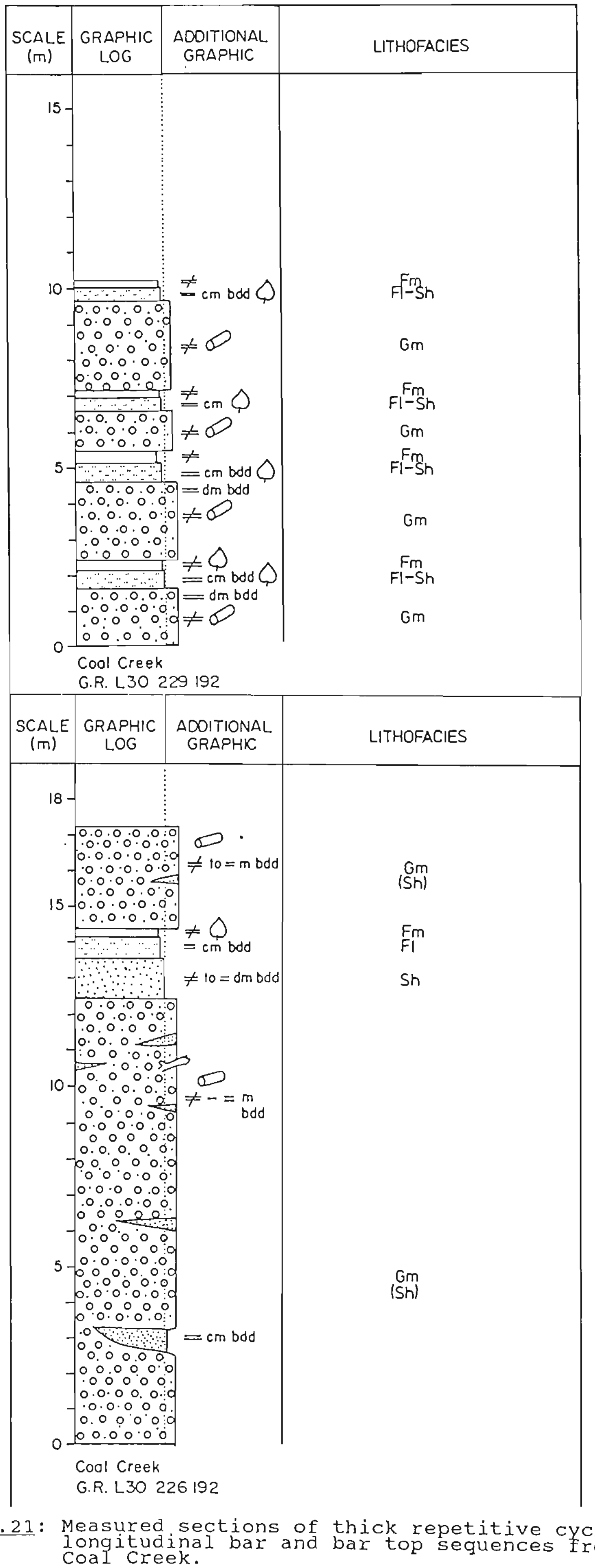
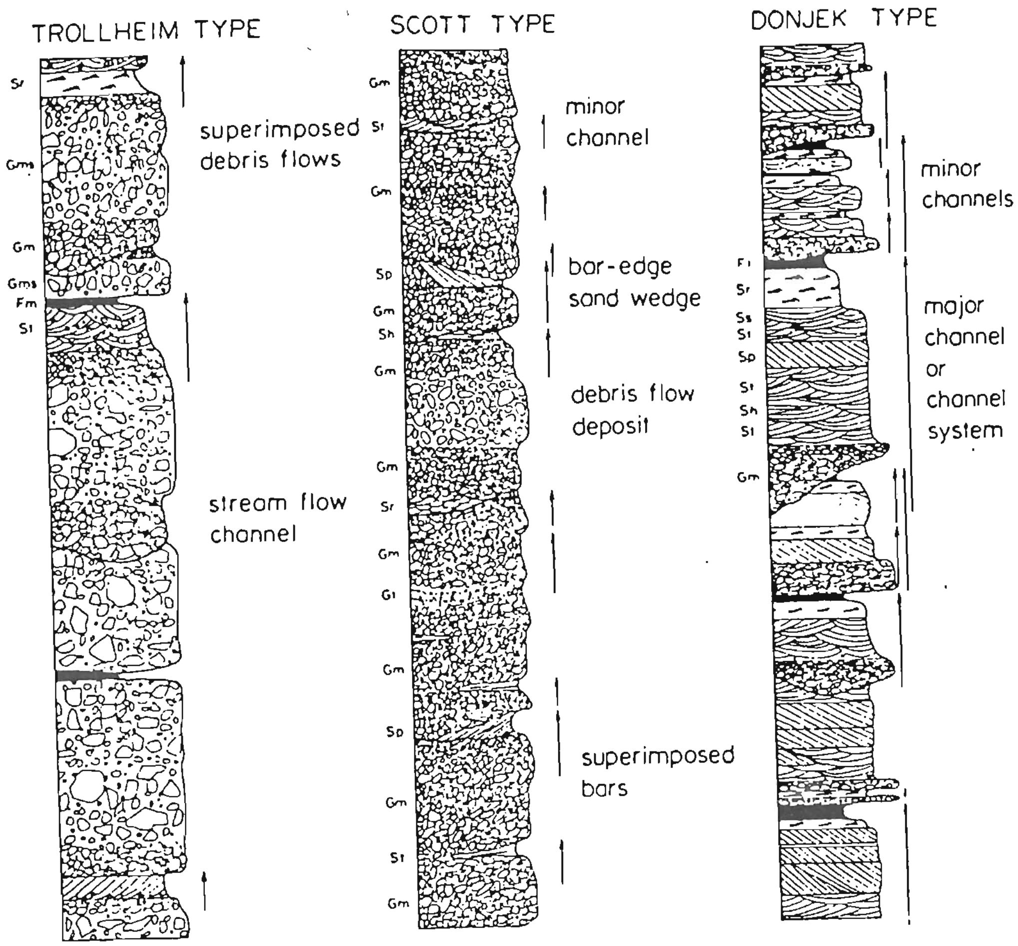


Figure 3.21: Measured sections of thick repetitive cycles of longitudinal bar and bar top sequences from upper Coal Creek.



	Trollheim type	Scott type	Donjek type
Name	Trollheim type	Scott type	Donjek type
Environmental setting	proximal rivers (predominantly alluvial fans) subject to debris flows	proximal rivers (including alluvial fans) with stream flows	distal gravelly rivers (cyclic deposits)
Main facies	*Gms, Gm*	*Gm*	*Gm, Gt, St*
Minor facies	*St, Sp, Fl, Fm*	*Gp, Gt, Sp, St, Sr, Fl, Fm*	*Gp, Sh, Sr, Sp, Fl, Fm*

Figure 3.22: Vertical profile models for the three principal types of gravel-dominated braided river deposits. Facies codes are given in Table 3.1 (From Miall, 1978; Rust, 1978).

ii) <u>Sequence M : Mudstone-dominated lithofacies sequence</u>.

Thick exposures of this sequence are locally common in the Camp Member (e.g. lower Coal Creek, Hart Creek), and two representative measure sections are provided (Figures 3.23 and 3.24). Lithofacies Fm is dominant in these sequences, and the characteristic vertical profile is:

Fl -> Fm -> Cd/Cl -> Fm

Mudstones within this vertical profile are always thick, and uninterrupted sections in excess of 25m thickness have been observed (e.g. Hart Creek). The thick mudstone-dominated sections are inferred to represent fine-grained overbank deposits. Well preserved leaves, stems, rootlets and frequent, generally thin, Type C coal seams (Section 6.6), are suggestive of sedimentation within a low to very low energy overbank setting. Beds of finely laminated siltstone (lithofacies Fl) are interpreted as distal overbank flood sedimentation, within the flood plain environment.

Coarse grained lithofacies are commonly interbedded with the thick sections of fine grained sediment. Thick beds (1.75-3m) of massive sandy conglomerate, interbedded with thick mudstone units, produce a characteristic lithofacies sequence:

Fm -> Sh -> Gm (minor Gms) -> Sh -> Fl -> Fm

These conglomerate units are always massive, and in some outcrops matrix-supported (lithofacies Gms). The absence of internal structures such as reactivation surfaces, grading, imbrication and sand wedges, suggests that these conglomerate beds were not deposited as braid bars. The abrupt incoming of conglomerate beds within the mudstone sections, their sheet-like geometry in relatively well exposed sections of the lower Camp Member at Coal Creek, the relatively uniform thickness (1.75-3m at every outcrop), and the characteristic massive to locally clast-supported conglomerate fabric suggests that these beds may represent "debris flow/sheet-flood" crevasse-splay deposits.

The thick conglomerate horizons are therefore interpreted as conglomeratic crevasse-splay deposits, which periodically inundated the overbank regions. Similar associations of fine grained flood plain deposits with coarse grained units

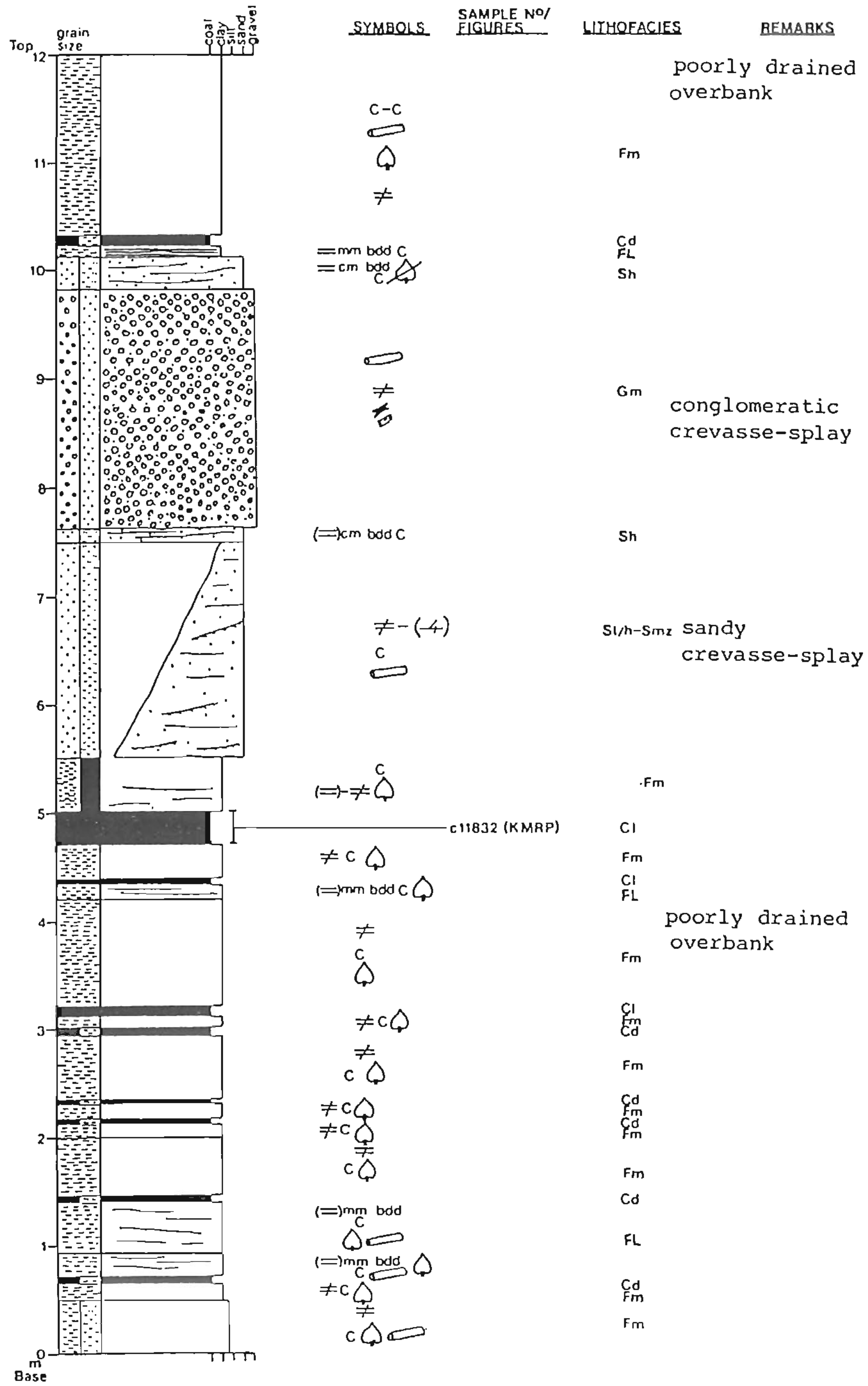


Figure 3.23: Measured section of mudstone dominated lithofacies sequence from lower Coal Creek.

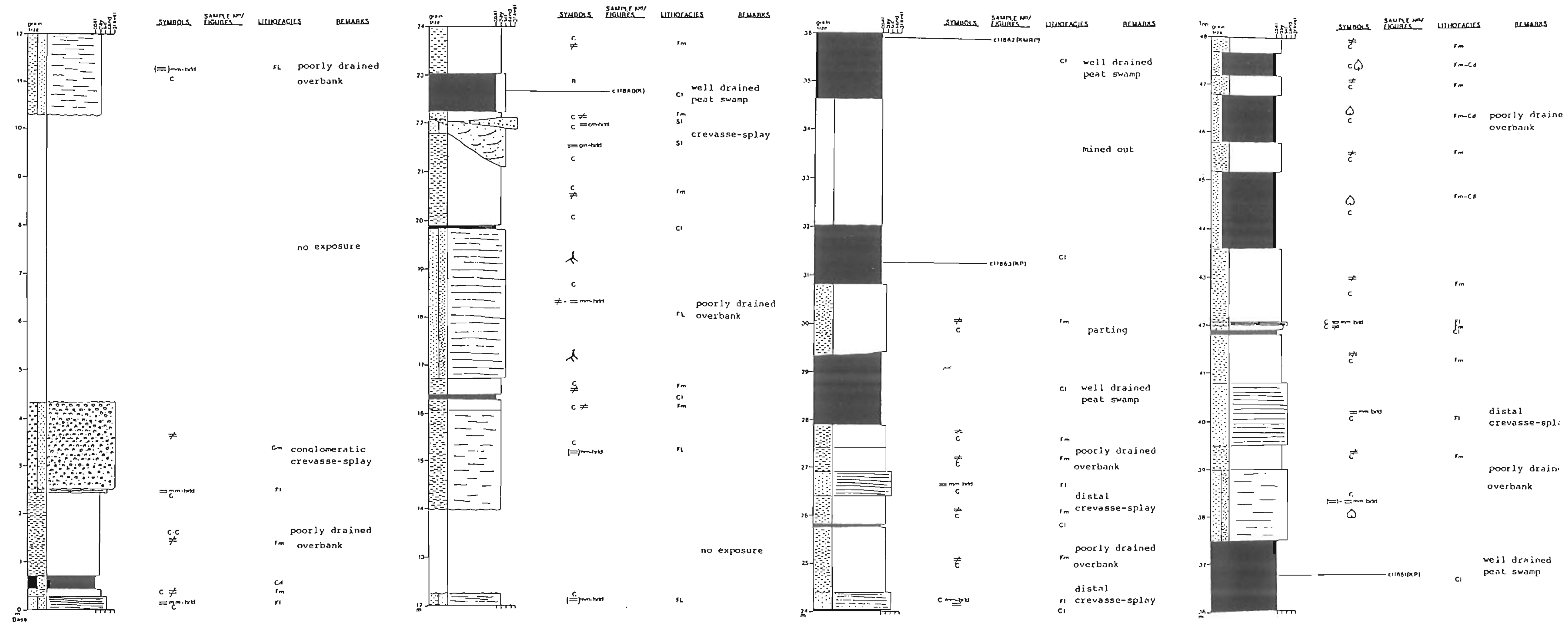


Figure 3.24: Measured section of mudstone dominated lithofacies sequence from Hart Creek.

are described in the literature by Heward (1978) and Rust (1978), within alluvial fan deposits.

Cross-bedded medium to fine sandstone units also commonly occur within the mudstone lithofacies sequences. These sandstones are interpreted as either sandy crevasse splay deposits, or distal equivalents of the conglomeratic crevasse-splays.

iii) Lateral Distribution of Lithofacies Sequences in the Camp Member

In Figure 3.25, all outcrops of the Camp Member (and some from the Thomson Member) are classified as either lithofacies sequence M (mudstone dominant), or C (conglomerate dominant).

Sequence C is predominantly restricted to the Brown/upper Coal Creek area, constituting all the upper Camp Member at Coal Creek. Sequence M dominates the Gorgy Creek, lower Coal/Camp Creek, and Hart/Shag Creek areas. At Gorgy Creek sequence M constitutes almost all exposures of the Camp Member, while it dominates the lower Camp Member only at Coal Creek.

The spatial distribution of the two lithofacies sequences is inferred to be an original depositional feature. The Camp Member was previously interpreted to represent a humid alluvial fan, characterised by both rapid sedimentation and syndepositional subsidence. Alluvial fans form localised fan-shaped deposits radiating downstream from an associated mountain front (Reineck and Singh 1980, Diessel 1984).

Concentration of channel deposits within restricted areas is a common feature of sedimentation within alluvial fan environments (Galloway 1976, Heward 1978, Wescott and Ethridge 1980, Reineck and Singh 1980, Diessel 1984; Figure 3.25a), usually resulting from a point source for the sediments, and/or sediment by-pass mechanisms such as lateral channel restriction by tectonic controls (Newman J. 1985), natural levees (Reineck and Sing 1980), or vegetation (Holden 1982a). Both mechanism are probable controls on the lateral distribu-

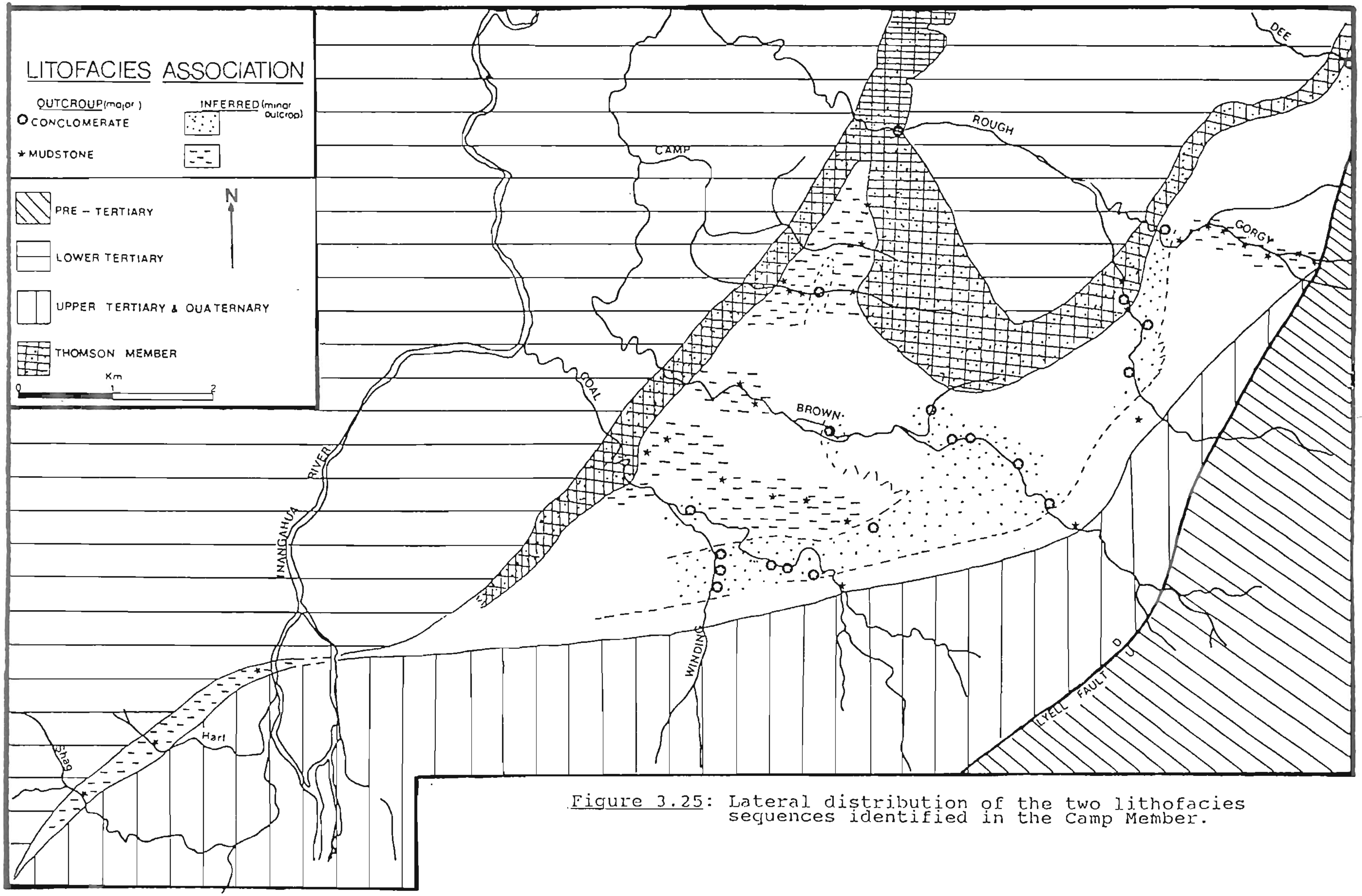


Figure 3.25: Lateral distribution of the two lithofacies sequences identified in the Camp Member.

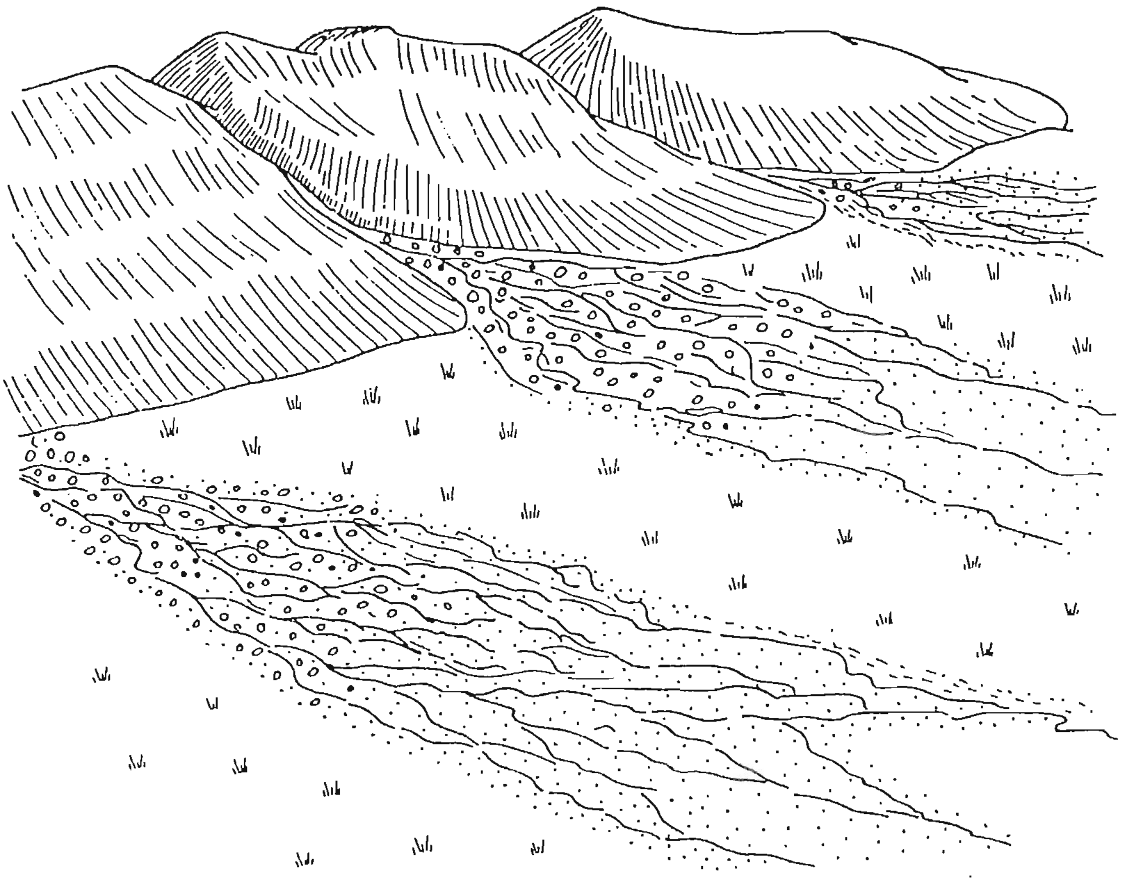


Figure 3.25a: Cartoon showing sediment by-pass in piedmont settings (from Diessel 1984). A similar mechanism is proposed for the distribution of lithofacies sequences in the Camp Member.

tion of channel sediments within the Camp Member, given the inferred paleoenvironmental setting of both high sedimentation rates and rapid subsidence, inferred from the lithostratigraphy.

South of Gorgy Creek, channel deposition in the lower Camp Member was restricted to the Rough/Brown Creek area, but was more widespread during deposition of the upper Camp Member, to include the Coal Creek area as well. Thick overbank sequences dominated by mudstone developed locally within the alluvial fan environment, due to lateral channel restriction, coupled with rapid syndepositional subsidence. Similar mechanisms for producing thick overbank sediments associated with coarse braided channel deposits have been proposed by McLean and Jerzykiewicz (1978), Friend (1978), and Diessel 1984.

The distribution of sandstone within the Ram Creek Member (Figure 2.5) also suggests restricted sediment supply, with thick, massive sandstone in the Brown/Coal Creek area corresponding to a probable sediment source. The mudstone-dominated facies of the Ram Creek Member in the upper Rough Creek area (Section 2.2) corresponds to a thick Thomson Member (Figure 2.5), and a dominance of overbank sediments at Gorgy Creek, possibly indicating a "fan-margin" (i.e. an area removed from active channel regions). Local thickening of the Thomson Member in this area was interpreted previously as probably resulting from an autocyclic transgressive phase produced by channel switching on the two active fan regions defined by sandstone thickness/distribution within the Ram Creek member.

3.3.3 Donkey Member

Three detailed measured sections are provided for the Donkey Member;

i) Giles Creek Mine:

ii) DH 118 (Appendix 12):

iii) Fletcher Creek Mine:

i) Giles Creek Mine

Figure 3.26 provides a detailed measured section for the interseam sediments separating two thick coal seams at the Giles Creek Mine.

The base of the section comprises distinctly banded coal (Type=AB, see Section 6.3), with frequent thin, clastic sedimentary partings, and thin lenticular, siliceous partings (described in Section 5.4). Thin beds of relatively coarsely ripple-laminated sandstone (lithofacies Sr), interbedded in the basal coal seam, are inferred to represent proximal crevasse-splay deposits (R. Flores, pers. comm.), whereas many of the thin massive mudstone beds (lithofacies Fm) may represent distal crevasse-splay deposits or periods of relatively rapid swamp subsidence, and/or very poor drainage.

The basal coal sequence is gradationally overlain by approximately 13m of sediment, comprising lithofacies Sr and distinctly lenticular beds of lithofacies Smz (Figure 3.27). Lithofacies Sr comprises finely ripple laminated sandstone, with fine rootlets and burrows, and is inferred to represent levee deposits. Lenticular beds of lithofacies Smz, comprising poorly sorted, silty fine to very fine sandstone, are interpreted as abandoned crevasse-splay channels, similar to those described by Horne et al. (1978) from Carboniferous deltaic sediments, with the abandoned crevasse channel within the levee being rapidly in-filled with poorly sorted sandstone of lithofacies Smz. The thick sequence of lithofacies Sr and Smz is therefore interpreted as a levee environment, with frequent levee breaching evidenced by the large number of abandoned crevasse channels.

The levee sequence is overlain, conformably in some places and erosionally in others, by a thick sequence (13m) of festoon cross-bedded sandstone (lithofacies Stf), inferred to represent dune bedforms deposited within aggrading channel sequences (R. Flores, pers. comm.). No other lithofacies has been identified within this cross-bedded sandstone sequence. Distinct breaks evident in the cross-bedding pattern (Figure 3.5) mark the base of new channel deposits, and imply a multi-channel sequence.

Figure 3.26: Measured section for interseam sediments at Giles Creek Mine.

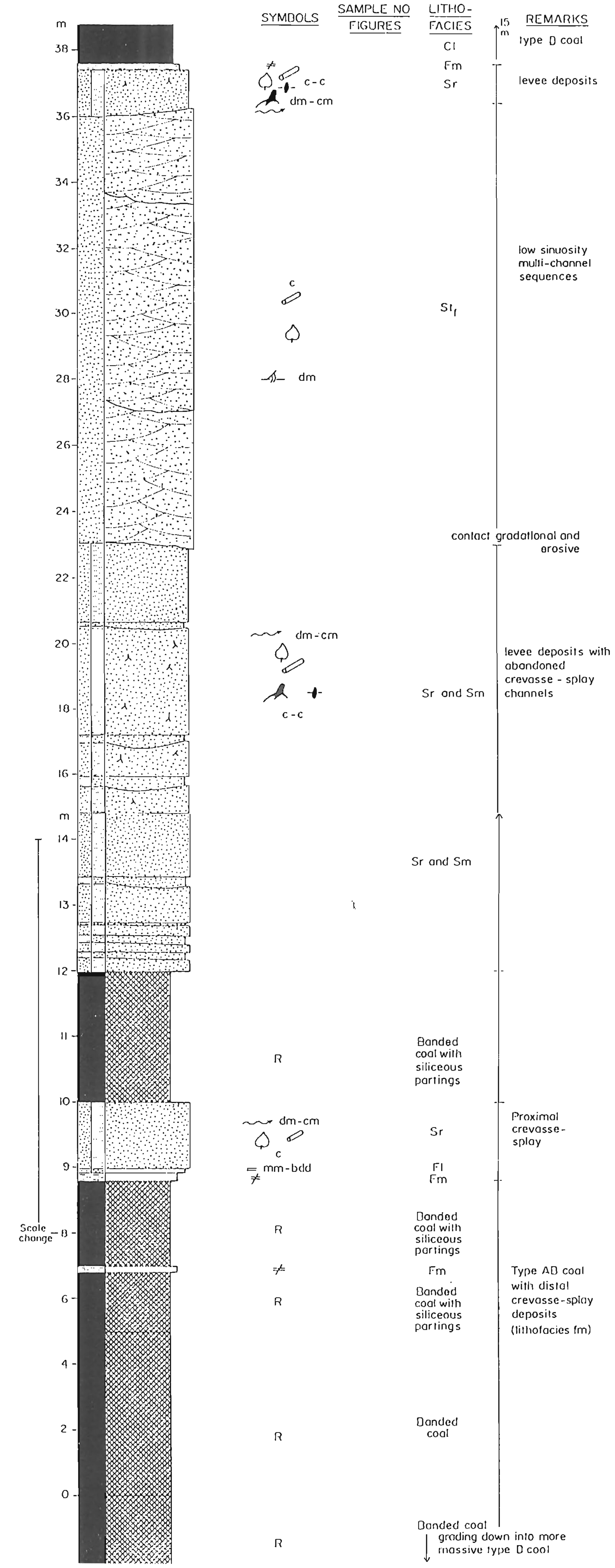


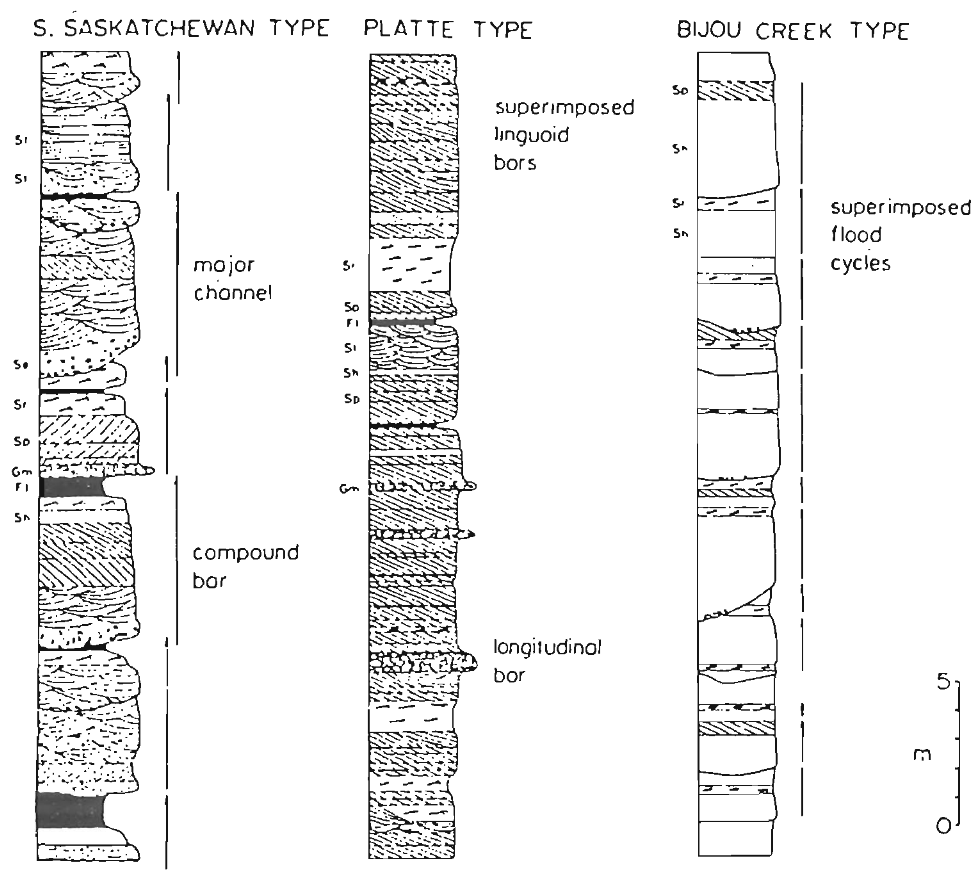
Figure 3.27: Lenticular beds of massive, silty sandstone (lithofacies Smz), interbedded with finely, ripple laminated sandstone (lithofacies Sr); interpreted to represent abandoned crevasse-splay channels within a levee sequence. Locality= Giles Creek Mine.

The multi-channel sandstone sequence is abruptly overlain by thick (locally up to 15m), relatively massive, very clean coal (Type=D, section 6.3). This thick coal sequence is inferred to represent a relatively well drained overbank swamp, which formed directly above an abandoned channel system.

Classification of paleochannel behavior and type from vertical sequence analysis can be extremely difficult, and at times unreliable (Miall 1977, Jackson 1978, Cant 1978, Allen 1983). The vertical sequence observed at Giles Creek comprises a number of sub-environments: proximal and distal crevasse-splays, levees, channels, and relatively well drained and poorly drained overbank swamps. The section described does not unambiguously fit currently proposed models for either sand-dominated meandering or braided stream environments (Figures 3.28 & 3.29).

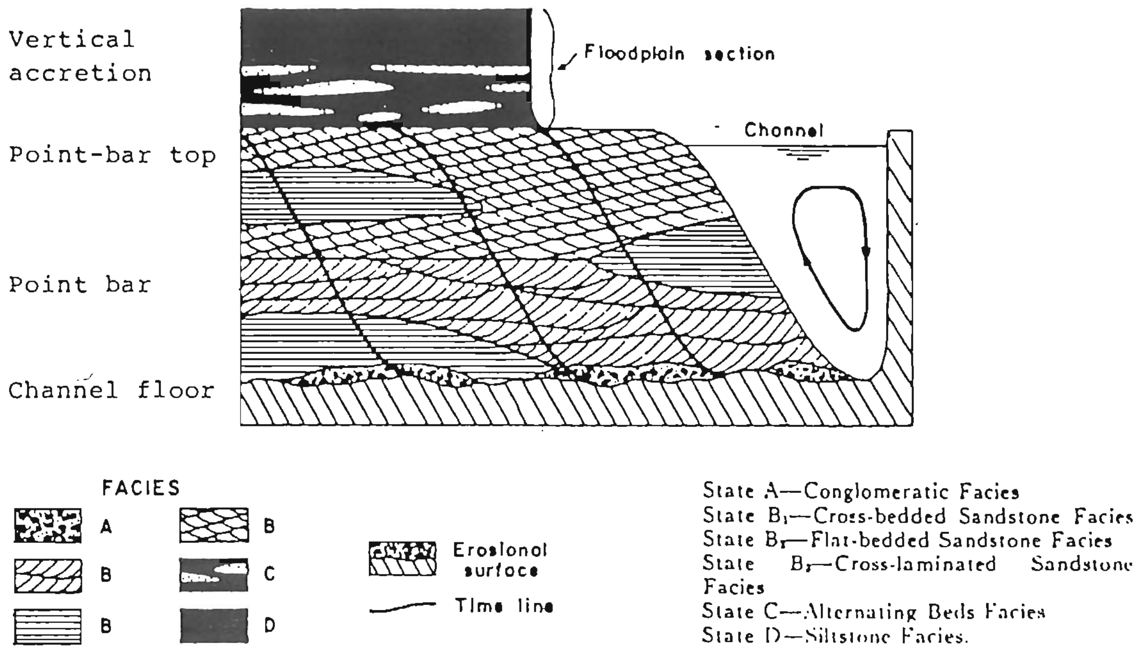
The thick sequence of channel-fill sandstones (Lithofacies Stf) resembles some of the channel-dominated vertical sequences identified within the braided Battery Point Formation by Cant and Walker (1976), the braided South Saskatchewan River (Cant 1978), or the sandstone-dominated "transitional sequence" identified by Jackson (1976) for the meandering Wabash River (Figures 3.28 and 3.29). Jackson (1978) evaluated commonly cited sedimentological criteria for distinguishing meandering and non-meandering streams, and found many criteria to be ambiguous, with few features diagnostic of either environment (Table 3.2).

The absence of epsilon cross-stratification, and the multi-storey internal geometry of the cross-bedded sandstones, is tentatively inferred to indicate low sinuosity river channels (Allen 1983, R. Flores pers. comm.), with moderately well developed levees. Frequent levee breaching and periods of channel abandonment are also suggested by the mine section, however further classification of channel type is not attempted in view of the ambiguous nature of data.

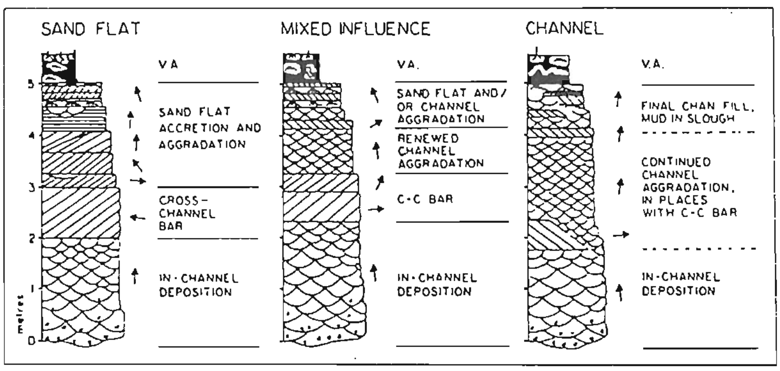


Name	South Saskatchewan type	Platte type	Bijou Creek type
Environmental setting	sandy braided rivers (cyclic deposits)	sandy braided rivers (virtually non cyclic)	Ephemeral or perennial rivers subject to flash floods
Main facies	*St*	*St, Sp*	*Sh, Sl*
Minor facies	*Sp, Se, Sr, Sh, Ss, Sl, Gm, Fl, Fm*	*Sh, Sr, Ss, Gm, Fl, Fm*	*Sp, Sr*

<u>Figure 3.28</u>: Vertical profile models for the three principal types of sand-dominated braided river deposits. Facies codes are given in Table 3.1 (from Miall, 1978; Rust, 1978).



Multiple composite fining-upwards cyclothem - the meandering river facies model. (In the legend, the B's are B_1, B_2 and B_3 respectively; after Allen, 1970.)



The range of facies sequences which could be produced by deposition in the river. The arrows represent only one of the possible paleocurrent patterns, with the average channel direction being represented by a vertical arrow. Muddy vertical accretion deposits with lenses of sand containing ripple and convolute laminations cap each sequence. From Cant and Walker (in press).

Figure 3.29: Comparison of multiple composite fining-upward cyclothem of the meandering river facies model (after Allen, 1970.), with the range of facies sequences which could be produced by deposition within a sandy braided river model such as the Battery point Formation (after Cant, 1978).

COMMONLY CITED SEDIMENTOLOGICAL CRITERIA FOR FLUVIAL DEPOSITS

	Meandering	Non-meandering
Vertical sequence of lithofacies	Fining-upward cycles (of grain size and sed. structures)	No consistent sequence
Fine member	Normally common and appreciably thick	Uncommon and thin
Rock gravel in coarse member	Small amounts; few large clasts	Can be abundant, with large clasts
Scroll bars	Common	Absent
Epsilon-cross stratification	Common	Absent
Scouring surfaces in coarse member	Uncommon	Abundant
Channel-fill mud deposits	Common, esp. in muddy streams; long and arcuate	Minor; short
Chute-fill and chute bars	Expected in "coarse-grained" streams	Uncommon
Natural levees	Often prominent	Minor
Dispersion of current indicators	Large, often >180^{o}	Small, often <90^{o}
Exhumed meander belt	Can be expected in proper sections	Absent
Continuity of sand and gravel beds (in coarse member)	Often great, with little lateral change in texture	Beds often lenticular and discontinuous

Table 3.2: Commonly cited sedimentological criteria for distinguishing sediments of meandering and non-meandering streams (from Jackson, 1978).

ii) <u>Drill hole 118</u>

The basal 44m of the Donkey Member in DH 118 (between 134.25-178.25m, Figure 3.30) has major lithostratigraphic similarities with the measured section for the base of the coal measures at Giles Creek Mine.

In DH 118 this basal interval comprises a relatively thick sequence of interbedded coal (of variable ash content) and carbonaceous mudstone (lithofacies Fm/Fl), with occasional beds of lithofacies Sr (relatively coarsely ripple laminated). This sequence is interpreted as a poorly drained overbank swamp environment, with frequent crevasse-splay deposition.

The sediments overlying the basal coal sequence (from 150-159m) are dominated by cross-bedded sandstones (lithofacies St and Stf; festoon cross-bedding was identified in some core sections), and ripple laminated sandstone (lithofacies Sr). These sandstone units are inferred to represent channel and levee sediments.

The channel/levee sequence is conformably overlain by a second thick sequence of overbank mudstone (lithofacies Fm and Cd), and clean coal (lithofacies Cl; ash contents in Appendix 8). These two lithofacies associations are inferred to represent relatively poorly drained, and well-drained overbank swamps respectively.

The interseam sediments in DH 118 show greater cyclic repetition than in the mine section, with at least three channel cycles identified between the basal seam and the second seam at 150-159m. Major periods of channel abandonment coupled with rapid subsidence, are inferred to have resulted in thick overbank deposits interbedded with major channel sequences identified throughout DH 118 (Appendix 12). Relatively well-drained swamps (with low ash coal) developed locally directly above abandoned channel sequences (i.e. 110-112.6m), while poorly drained peat swamps occasionally developed in the overbank environments (eg. 128.81-136.10m).

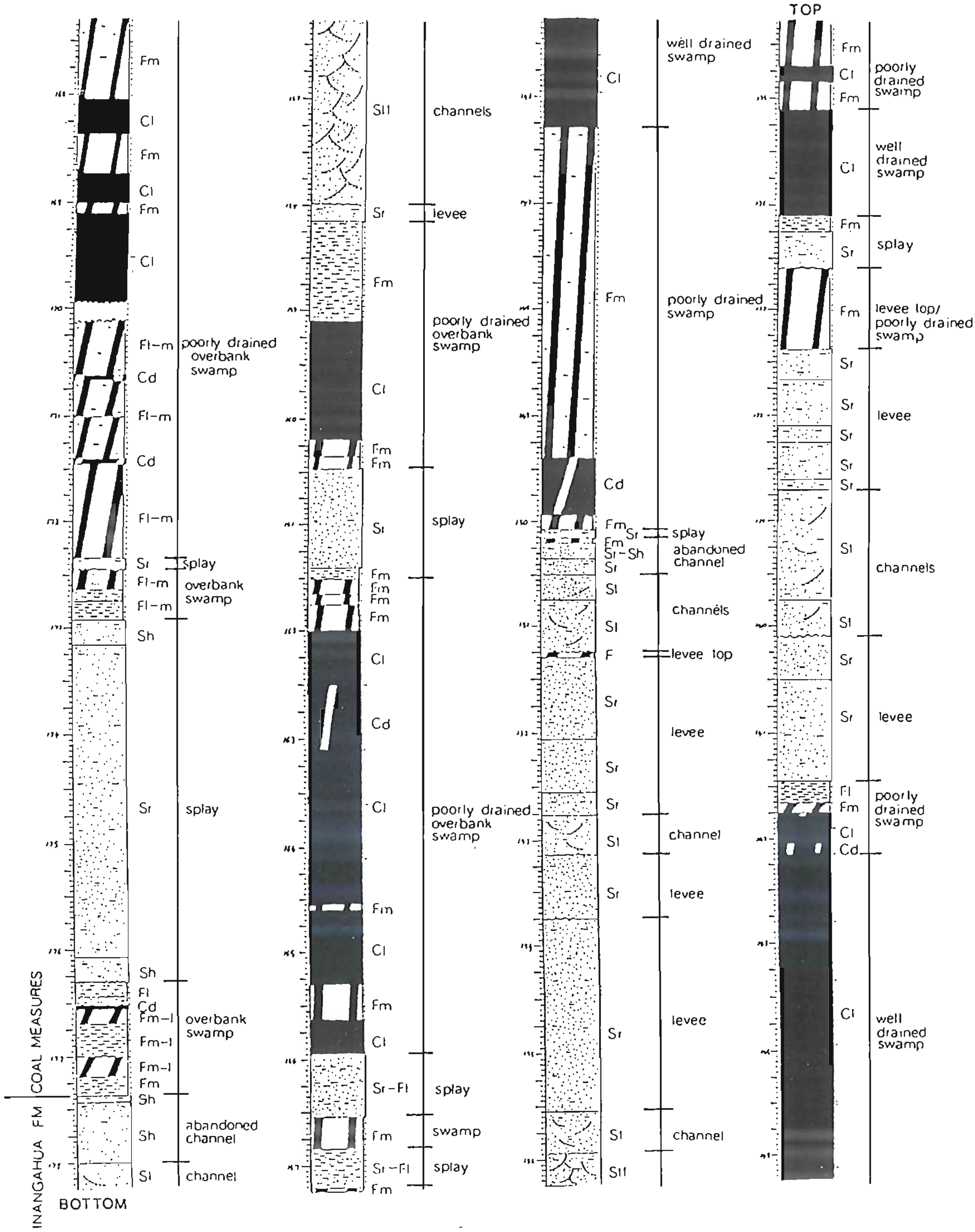


Figure 3.30: Lithofacies sequence within DH 118, from 134.25 to 178.25m.

The upper Donkey Member in DH 118 contains occasional, thin (<2m) beds of fine, sandy conglomerate at the base of channel sequences. This coarsening upward trend is similar to that noted for the Camp Member in the Coal/Brown Creek area (Section 2.3), and is inferred to represent a general trend of alluvial progradation.

iii) Mulligans Mine

Mulligans Mine provides excellent exposure of the northern-most outcrop of the lower Donkey Member. The structure present in the mine is mentioned briefly in Chapter 4.

A thick coal/mudstone horizon characterises the base of the Donkey Member at the mine, and gradationally overlies silty fine to medium sandstone of the Ram Creek Member (Figure 3.31). Lenticular, carbonaceous mudstone horizons (lithofacies Fm) within this basal coal seam are inferred to represent intra-swamp paleodrainage channels.

Intercalated within this thick coal/mudstone horizon is a series of distinctly lenticular, coarse grained, channel-fill deposits. The thick channel-fill which scours into the top of the coal seam comprises a series of fining upward cycles. Each cycle has an erosive base, marked by a thin, fine conglomeratic (maximum clast size <8cm) lag deposit (Lithofacies Gm), which generally fines laterally away from the channel centre. The dominant lithofacies of the channel-fill sediments are lithofacies Gm and St (pebbly cross-bedded sandstone). The channel sediments are abruptly overlain by carbonaceous mudstone, which is in turn overlain by festoon cross-bedded sandstones.

The lenticular nature of the channel sediments, their abrupt upper contacts, the absence of lateral accretion surfaces, and the multi-storey nature of the thick channel-fill sequences, are features consistent with low sinuosity rivers (Allen 1983).

The depositional environment of the lower Donkey Member at Fletcher Creek is inferred from lithostratigraphy to have been a poorly drained swamp/lagoon area, with low sinuosity

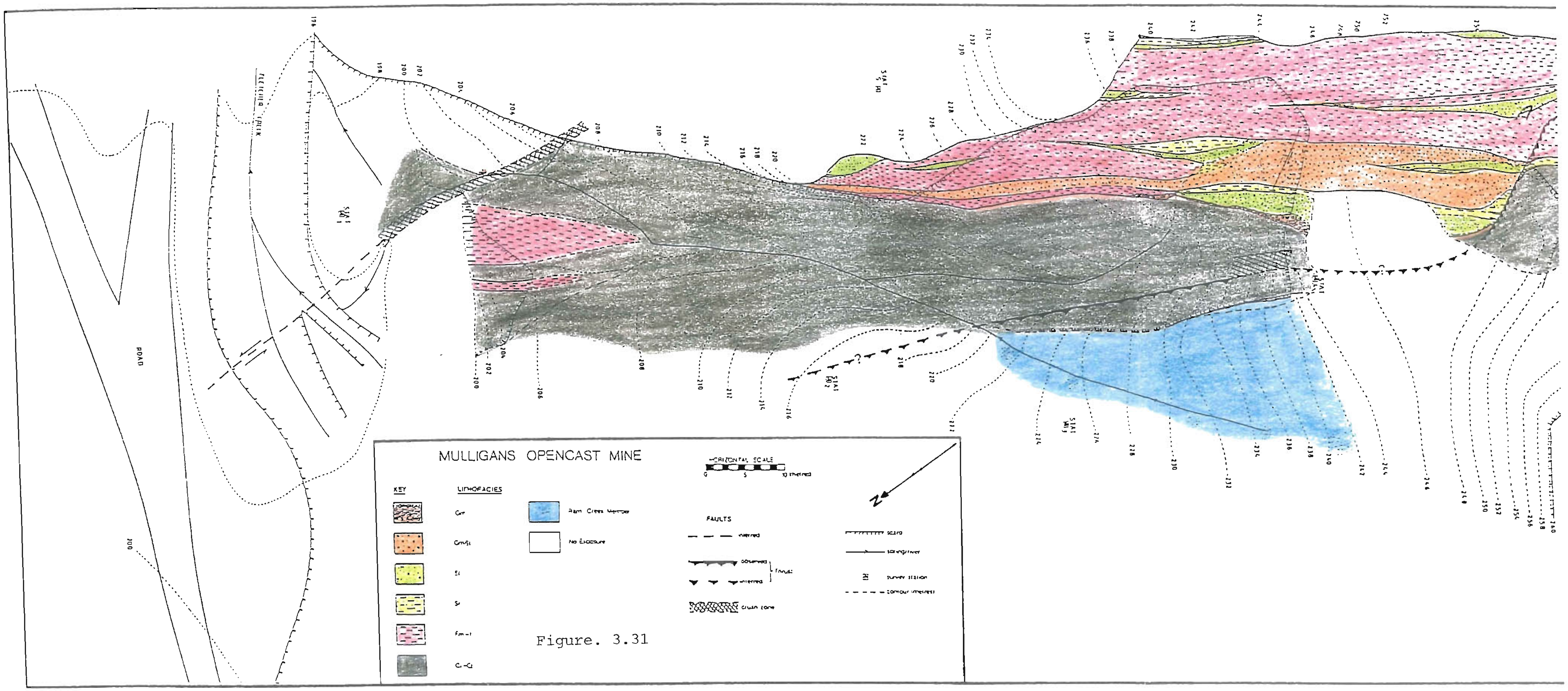

MULLIGANS OPENCAST MINE
HORIZONTAL SCALE
0
5
10 metres
KEY
LITHOFACIES
Ram Creek Member
No Exposure
FAULTS
inferred
observed
thrust
inferred
crush zone
scarp
survey station
N
ROAD

Figure. 3.31

rivers frequently entering the swamp environment. Outcrops further downstream (approximately 20m) show that this fine grained lagoonal/swamp lithofacies is overlain by a thick sequence of festoon cross-bedded channel sandstone.

CHAPTER FOUR

STRUCTURE

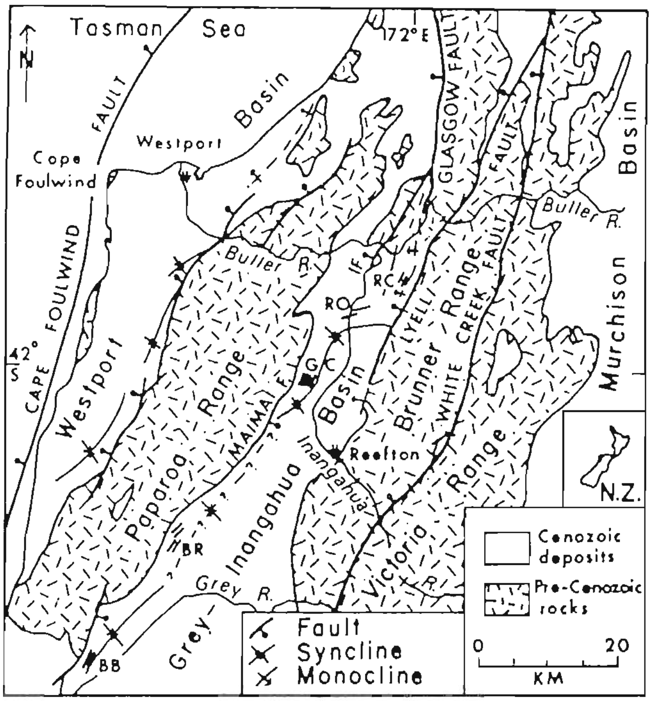
4.1 INTRODUCTION

The Inangahua Valley constitutes the northern extension of the partially fault bounded, north-north-easterly trending Grey-Inangahua Depression (Suggate 1957). The structure of the Depression is relatively simple, being dominated by open asymmetric synformal folds, and north-north-easterly trending normal and reverse faults (Figure 4.1). The following discussion is intended to complement the geological interpretation provided on the accompanying maps, and is not intended as a detailed structural analysis of the Inangahua Valley.

4.2 FOLDING

The Mawheraiti Syncline (Suggate 1957) is the major structural feature of the Inangahua Valley. Within the study area the Mawheraiti Syncline is an open, asymmetric, steeply inclined synform. The syncline axis extends from the upper Maimai Valley (Suggate 1957) north along the western margin of the Inangahua Valley to McMurray Creek, then swings east into the Coal Creek area, eventually terminating against the Lyell Fault at Rough Creek.

Between Inangahua Landing and the lower Giles/Stony River area, dips within the Tertiary sequence increase in an easterly direction from upfolded Pororari Group basement (Wellman 1950) and Paleozoic granite of the Paparoa Range, towards the Mawheraiti Syncline axis (dips are approximately 20^0 near the basement contact, and increase to $70\text{-}80^0$ in late Tertiary/early Quaternary sediments near the syncline axis). As a result of this folding, the thin discontinuous belt of coal measures south of Inangahua Landing dips steeply east-south-east. In the mid Giles Creek area sedimentary onlap relationships, coupled with a swing in the trend of the Mawhe-



<u>Figure 4.1</u>: Regional structural setting of the Inangahua Valley (from Yeats, 1985). Heavy lines are faults with bar and ball on the downthrown side. Arrows on monoclines point to the downwarped side. Short heavy lines show flexural-slip faults in the Grey-Inangahua Basin:
BB, Blackball;
BR, Big River;
GC, Giles Creek;
[Rough Creek (RC), Rotokohu (RO), and Inangahua (IF faults moved in 1968.]

raiti Syncline axis, produce a local flattening of dips within the coal measures (map 3 and cross section B-B' in map pocket.)

North of Brown Creek the structure of the Rotokohu Coal Measures is dominated by the Inangahua Syncline in the central part of the valley, and two smaller non-cylindrical, antiformal folds further east adjacent to the Lyell Fault.

The Inangahua Syncline (Wellman 1950) is an open, non-cylindrical, gently plunging to horizontal synform (predominantly plunging south at around 10^0, but locally plunges north at a very shallow angle [$<5^0$] at Brown Creek). Nathan (1978a) traced the Inangahua Syncline north from Brown Creek across the Buller River into the Pensini Creek area. Within the study area the western limb dips east at a moderate angle of between $35\text{-}45^0$, and is abruptly terminated north of the Buller River by the Inangahua Fault (Nathan 1978a). The eastern limb is sub-horizontal to gently dipping south of the Buller River, with parasitic antiform and synform folds developed in the Camp Creek area.

The Glasgow Anticline (Wellman 1950) occurs east of the Inangahua Syncline between Brown and Rough Creeks, but cannot be traced north into Dee Creek. The Glasgow Anticline is a gentle, non-cylindrical, steeply inclined, horizontal antiform, and is inferred to merge into the monoclinal hinge mapped in the mid Coal Creek area (map 2). A second non-cylindrical antiformal fold occurs north of Gorgy Creek, and is characterised by a very steep to locally overturned eastern limb adjacent to the Lyell Fault, and a gentle, westerly dipping western limb.

An open, non-cylindrical, steeply inclined synform occurs in the Dunphy/St Helena Creek area. The sub-horizontal western limb of this synform dips very gently west at $3\text{-}5^0$, while the eastern limb generally dips very steeply west ($85\text{-}90^0$) and is locally overturned.

4.3 FAULTING

4.3.1 Major Faults

The north-north-easterly trending Lyell Fault (Wellman 1950) defines the eastern margin of the Inangahua Valley north of Landing Creek. The Lyell Fault is a major, active (most recent movement occurred during the 1968 Inangahua Earthquake; Lensen and Otway 1971) normal fault, with pre-Tertiary basement of the Brunner Range upthrown relative to the Tertiary sequence within the valley bottom. The southern extent of this fault is problematic, and is discussed further in Section 4.4.

The north-north-easterly trending Maimai Fault (Suggate 1957) occurs in the south-western corner of the Inangahua Valley. This fault was not observed to crop out in the study area, but is inferred from mapping further south by Suggate (1957), and White (pers. comm.), who map the Maimai fault from the upper Giles Creek area south to Maimai Creek. The Maimai Fault is a major reverse fault, with Paleozoic granite upthrown relative to Tertiary sediments.

According to Suggate (1957), the Maimai fault combines with two further faults in Giles Creek to fault-out the Tertiary sequence. Suggate's map required this complex fault pattern because of the assumption of constant bed thickness for upper Tertiary sediments on the south-western side of the Inangahua Valley. This interpretation is disputed in this thesis, which documents erosion of most of the Tertiary sequence in the Giles Creek area by the distinctly angular regional Wanganui unconformity.

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* P. White (pers. comm.) suggests Mawheraiti Fault (Henderson 1917) has precedence over Maimai Fault, but the former is never referred to in the literature, while the latter has become an accepted geological name during the past 30 years and is retained in this thesis to avoid unnecessary confusion.

The Inangahua Fault (Nathan 1978a; synonym=Glasgow Fault- Wellman 1950, Lensen and Otway 1971) was not mapped during this thesis, and the outcrop pattern shown on the accompanying maps is taken directly from Nathan (1978a).

4.3.2 Minor Faults

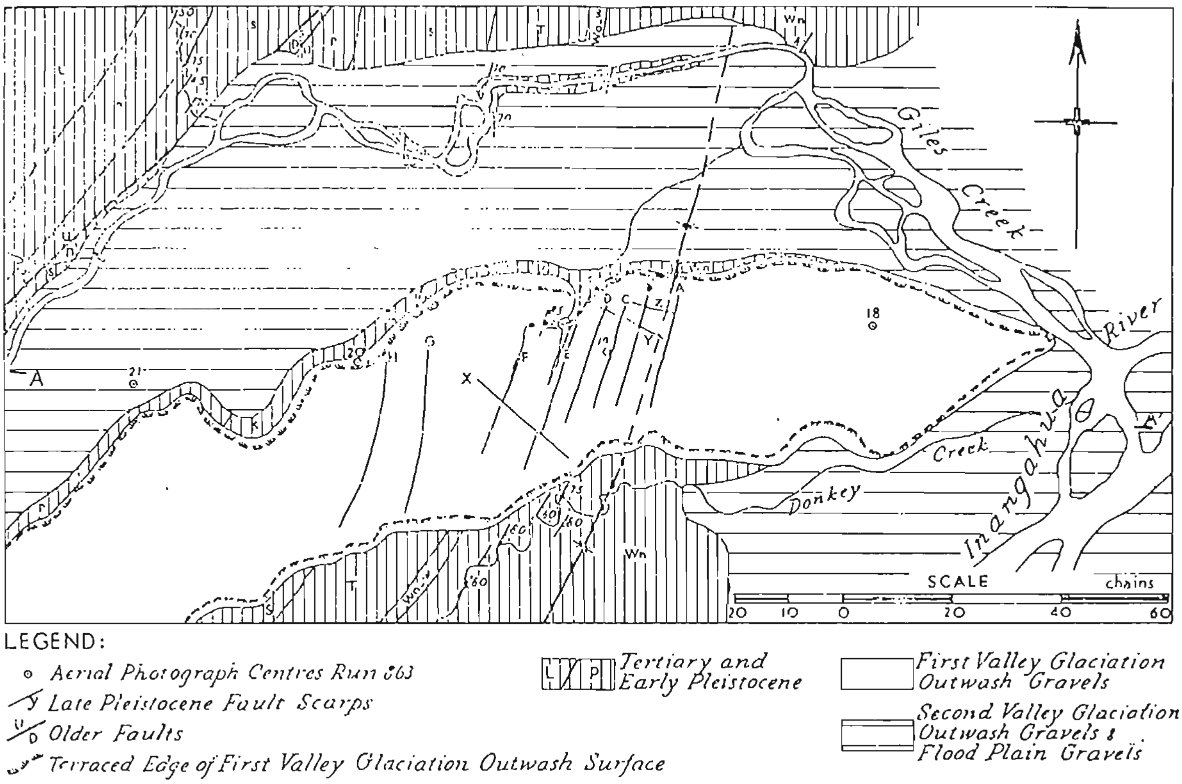
A number of minor faults have been recorded within the study area (Suggate 1957, Lensen and Otway 1971, Nathan 1978a). Most minor faults strike sub-parallel to underlying poorly indurated, steeply dipping, late Tertiary to early Quaternary sediments, and are upthrown towards subjacent synform axis. These faults are interpreted as bedding plane slips (Suggate 1957, Yeats 1985) formed in response to flexure-slip folding (Ramsay 1967, Yeats 1985; Figure 4.2).

A zone of predominantly reverse faulting occurs within the Inangahua Formation and Rotokohu Coal Measures from Stony River north to Fletcher Creek. Variably dipping reverse faults striking sub-parallel to bedding crop out at Stony River (Figure 2.7; Map 2) and Fletcher Creek (Figure 3.31), while a series of reverse fault traces are shown by Nathan (1978a) within this area.

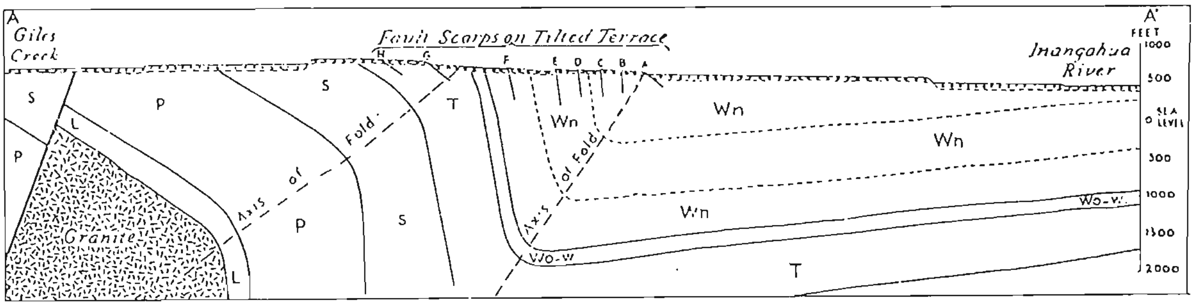
Minor strike slip faults are observed at Fletcher Creek (Figure 3.31; sinistral) and Giles Creek (K30 096055, dextral; and K30 085052, sinistral). North-westerly trending reverse faults are shown by Suggate (1957) to offset flexure-slip faults at Giles Creek (faults X, Y & Z Figure 4.2), with further examples shown on map 3.

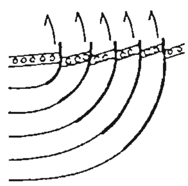
4.4 DEFORMATION HISTORY

The overall structural trend within the Inangahua Valley follows the north-north-east trend which characterises major structural elements of the West Coast (Suggate 1957, Laird 1968, Nathan and others 1986). The north-north-easterly trending Inangahua, Lyell and Maimai Faults strongly influence the style of folding evident within the valley, with up thrown basement resulting in strongly asymmetric folds within the Tertiary to lower Quaternary sequence. Laird (1968) proposed



A: Faulted outwash surface, Giles Creek.





B: Flexural-slip faults cutting an unconformable cover. Fault displacement vanishes at the synclinal axis. Scarp faces away from the synclinal axis, and cover beds are tilted toward the synclinal axis (after fig. 2 of Yeats 1982).

<u>Figure 4.2</u>: A) Flexure-slip faults at Giles Creek (from Suggate, 1957).
B) Mechanism for the development of flexure-slip faults (from Yeats, 1985).

a similar mechanism of basement overthrusting for the development of the asymmetric Grey Valley Syncline in the southern Grey-Inangahua Depression.

Folding of the Tertiary to early Quaternary sediments, and the development of much of the large scale faulting occurred during a period of major mid Pleistocene compressional tectonics, after deposition of the strongly folded Pliocene to lower Pleistocene Old Man Group, but prior to upper Pleistocene glaciations (Nathan and others 1986).

All small scale faulting noted previously in Section 4.3 appears to be related to this Pleistocene deformation. The absence of gullying in bedding plane faults developed in glacial terraces at Giles Creek suggests that these faults formed coseismically (Yeats 1985), and is consistant with the coseismic formation of similar fault traces during the 1968 Inangahua Earthquake (Figure 4.1; Lensen and Otway).

Reverse faults in the Stony River/Fletcher Creek area are interpreted as sub-parallel bedding plane thrusts. Ramsay (1967) notes that such faults may be quite common in the limbs of flexure-slip folds when intense shear strains develop where relatively competent beds are interbedded with relatively incompetent beds. The Inangahua Formation/Rotokohu Coal Measures contact in the Stony/Fletcher Creek area crops out at the transition from shallow to steeply dipping sediments, and is characterised by overthrusting of the relatively incompetent Ram Creek Member over competent coal at the base of the coal measures. These sub-parallel bedding plain thrusts were a major influence on underground mining of the basal Donkey Member seam at Mulligans mine (W. Brazil pers. comm.), and will create problems for any future mining and/or prospecting in the Stony/Fletcher Creek area. Reverse and strike slip faulting evident in steeply dipping Pliocene sediments at Giles Creek are probably related to local stresses created by overthrusting of Paleozoic basement on the Maimai Fault.

Both the south-eastern and south-western margins of the Inangahua Valley were active during the late Miocene, prior to deposition of the Pliocene Giles Formation. Mid (?) to late Tertiary faults are overlain by the Pliocene unconformity at Italians Creek (Suggate 1957), and probably at St Helena Creek/Larry River (the possible southern extent of the Lyell Fault). The marked angular unconformity between Rotokohu Coal Measures/lower Tertiary sediments, and Giles Formation on the western margin of the valley is interpreted as possibly resulting from the initiation of uplift within the region of the present Paparoa Range. Nathan and others (1986) suggest a similar local uplift within the area of the present Paparoa Range, as evidenced by early Pliocene "Moonlight beds" (Nathan 1978c) unconformably overlying Paleozoic basement at Moonlight Creek.

Uplift of the Victoria Range during the early Miocene (Nathan and others 1986), provided a local Greenland Group source area for the Rotokohu Coal Measures, and separated the Grey-Inangahua Depression from allochthonous Caples/Pelorus Terrane derived material which characterises Miocene to Pliocene sediments of the neighbouring Murchison/Maruia valley. Syndepositional faulting is inferred to have resulted in rapid thickness variations and abrupt changes in the style of sedimentation evident in early to mid Miocene sediments preserved in the Inangahua Valley (Chapters 2 and 3).

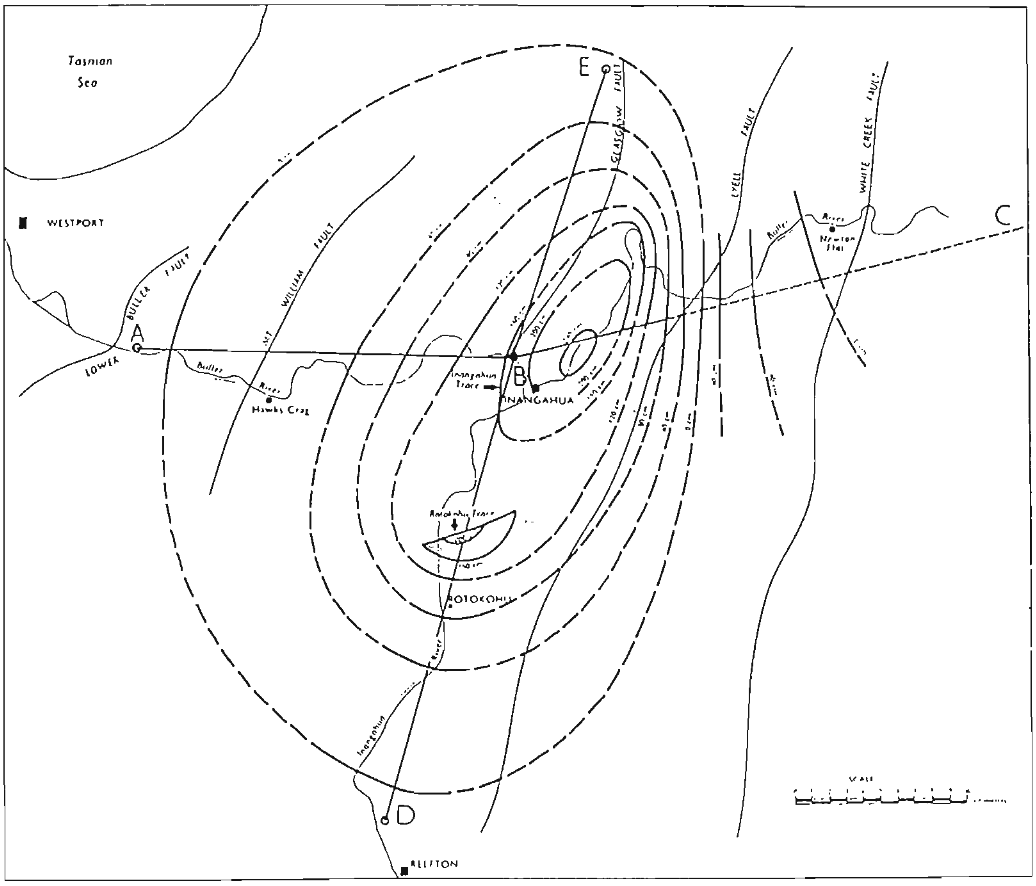
These lithosratigraphic features are oblique to the major north-north-east structural trend which controlled sedimentation on the West Coast during the early Cretaceous to early Tertiary, and may suggest a link between the style of early to mid Miocene sedimentation in the rapidly subsiding northern Inangahua, and the even greater rates of subsidence noted in the Murchison Valley (Nathan and others 1986).

The style of early Miocene sedimentation and syndepositional faulting suggests a local regime of extensional tectonics within the Inangahua/Murchison region, with probable compressional regimes in the Victoria Range area and east of the Alpine Fault in the Murchison area (Nathan and others 1986). The development of this rapidly subsiding basin in the northern Inangahua/Murchison area, associated with local regions of uplift may suggest a "pull-apart" mechanism for basin development, possibly resulting from early Miocene dextral strike slip movement on the Alpine Fault.

Suggate (1979) suggests a similar "pull-apart" mechanism for the origin of the Murchison Basin, although the precise details of Suggate's model (i.e. timing of movement, cause of the bend in the Alpine fault, relative position of rock units, etc) are disputed (eg. Cutten 1979). This early Miocene east-west structural trend has been concealed by the strong Pleistocene compressional tectonics, which has utilised the inherent north-north-east structural weakness of the West Coast region.

A major basement fault probably exists near Rotokohu, and is inferred to have had a major control on sedimentation within the valley. Evidence for this fault is suggested by,

a) rapid thickness variations within the early to mid Miocene sediments in this area, and the angular nature of the Pliocene unconformity near Inangahua Landing,
b) the abrupt change in the style of folding near this region,
c) the occurrence of bedding plane faults within this area during the Inangahua Earthquake (Figure 4.3),
d) the possible off-setting of the upper Pleistocene glacial sequence north of this area (Nathan pers. comm.).



Vertical deformation of the region resulting from the Inangahua Earthquake and its aftershocks.

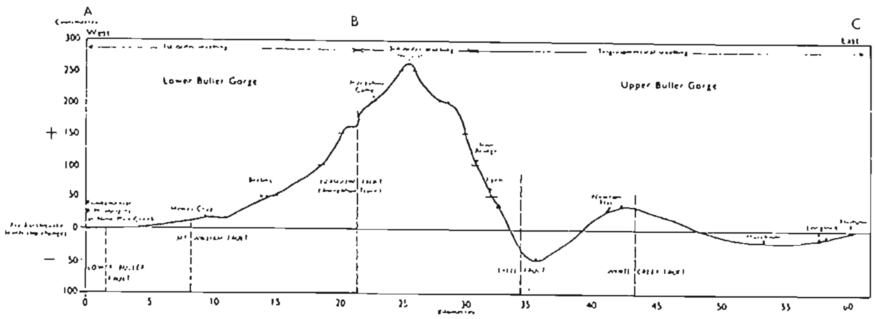


FIG. 3.—Cross-sectional West-East profile A-B-C

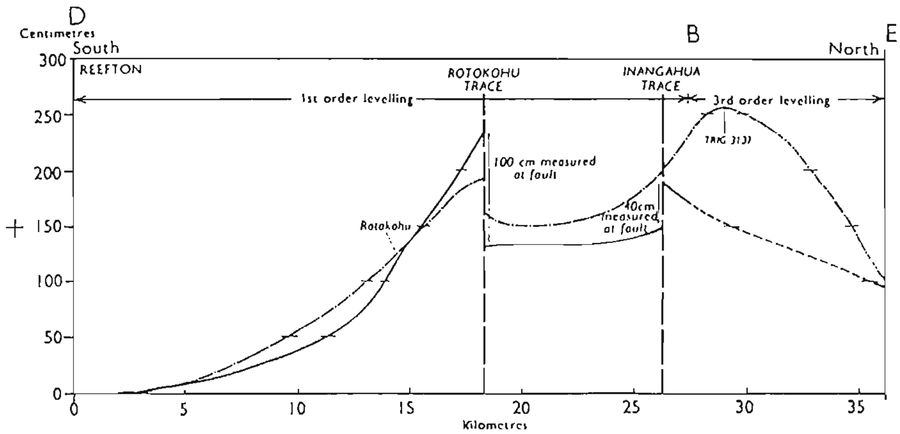


FIG. 4.—Cross-sectional South-North profile, D-B-E , together with profile along road (solid and dashed line).

Figure 4.3: Vertical deformation within the Inangahua Valley during the 1968 Inangahua Earthquake (from Lensen and Otway, 1971). Major flexure-slip faulting at Rotokohu occurs within the Giles Formation, and is inferred in this thesis to possibly reflect the presence of a major basement fault in this area.

CHAPTER FIVE

INORGANIC CONSTITUENTS AND SULPHUR IN ROTOKOHU COAL

5.1 INTRODUCTION

There is no universally accepted definition of the term mineral matter within coal, consequently some geologists extend the term to include all elements except organically derived or organically bound C, H, N and O (Renton 1982). This definition includes inorganic materials which are not true minerals, but are organically bound within the coal, and is useful with relatively low rank coals (<bituminous rank; ASTM classification) where significant proportions of the inorganic elements may be complexed to humic material.

Mackowsky (1968) classified mineral matter within coal into two basic categories, syngenetic or epigenetic, depending on the inferred mode of origin. According to this classification the syngenetic minerals include those minerals that accumulated concurrently with peat formation, up to those that formed in the "soft lignite" stage (Renton 1979). Minerals incorporated in coal during this stage may be of detrital, vegetal, or chemical origin, and commonly dominate the mineralogy of the coal ash. Because of the intimate relationship of many syngenetic minerals with the early biochemical stages of coalification, recognition of such minerals is pertinent to understanding the depositional environment of coal.

Epigenetic minerals form during the geochemical stage of coalification, commonly as a result of chemical precipitation from percolating solutions (Renton 1982). They occur as relatively coarsely intergrown fracture fillings, or as metasomatic replacement of macerals or syngenetic minerals. Since the formation of epigenetic minerals post-dates the biochemical stage of coalification, they cannot provide information pertinent to the depositional environment of the coal.

Although the classification outlined above appears definitive in theory, in practice it is less so (Renton 1982, Sykes 1985). Most minerals can be either syngenetic or epigenetic in origin (Mackowsky 1968, Renton 1982). Discrimination between and within the two mineral groups is based primarily on mineral matter form, and mineral-maceral relationships determined by microscope techniques (transmitted light, reflected light, and Scanning Electron Microscope). These criteria frequently provide ambiguous results, while geochemical techniques are generally unable to determine mineral-maceral relationships. As a result, the origin of some mineral occurrences in coal samples will not be adequately resolved.

Mineral matter within Rotokohu coals had not been analysed prior to this study. The approach adopted in this investigation is primarily a regional appraisal of the mineral matter mineralogy, form and distribution, with two samples included from the Giles Formation (samples 11816 and 11838).

Syngenetic and epigenetic mineral groups are discussed separately in this Chapter, with reference made to organically bound mineral matter where applicable. Sulphur is discussed separately, in view of its stratigraphically controlled distribution in Rotokohu coals, various forms, and economic significance in coal deposits. Finally, the high temperature ash chemistry is discussed, with reference to both the syngenetic and epigenetic origin of the various elements.

All coal samples analysed were from outcrop, with care taken to provide as fresh a sample as possible. The effects of weathering on various coal properties, including inorganic mineralogy, are well documented within the literature (Stach et al. 1982, Black 1984, Newman J. 1985, Newman N. 1985), and weathering must therefore be considered as a possible factor influencing the mineralogy and ash composition of the coals analysed in this thesis.

5.2 SYNGENETIC MINERAL MATTER

5.2.1 Detrital

Handspecimens of carbonaceous mudstone and carbominerite (20-60% mineral matter by volume; as defined by Stach et al. 1982, page 151) contain relatively coarse grains of quartz and muscovite, within a fine carbonaceous clay matrix. X-ray diffraction of low temperature ash (LTA) residues from these lithologies reveals a mineralogy dominated by quartz, relatively well ordered kaolinite and muscovite/illite, and feldspar (sample 11838), with pyrite present in some samples. With the exception of pyrite (Section 5.5), this mineral matter is inferred to be predominantly of detrital origin. These very high ash samples (samples 11818 and 11838) contain the greatest diversity of mineral matter observed within the samples analysed.

Coal occurring at the roof and floor of seams frequently contains a higher ash content than the intervening coal. This high ash content is commonly attributed to an increase in detrital minerals (e.g. Newman J. 1985). The roof and floor of Rotokohu coal seams are commonly distinctly gradational in outcrop (Figures 5.1 and 5.2), and have medium to very high ash contents (>10% db; ash classification as proposed by Bowen 1978, Table 5.3).

Microscopically these samples are characterised by distinct bands of thin telocollinite (well preserved plant tissue) interlayered with horizons rich in desmocollinite (degraded humic material), quartz and clay (Figure 5.3). The LTA mineral assemblage of these samples is usually dominated by quartz, and relatively well ordered kaolinite and muscovite (Appendix 9). Petrographically the quartz is generally fine to very fine rounded grains, and the enclosing macerals commonly show well developed compactional features, suggesting a detrital origin.

The occurrence of clastic sedimentary partings within coal seams commonly produces an increase in the ash content of the associated coal (Figure 5.4). Petrographic work and LTA analyses suggest that in Rotokohu coal the medium to very high

Figure 5.1: Gradational contact at the roof of the 2nd seam, Giles Creek Mine. Note the abundance of thin siliceous partings (white bands; arrowed), as the seam passes gradationally into channel sandstones.

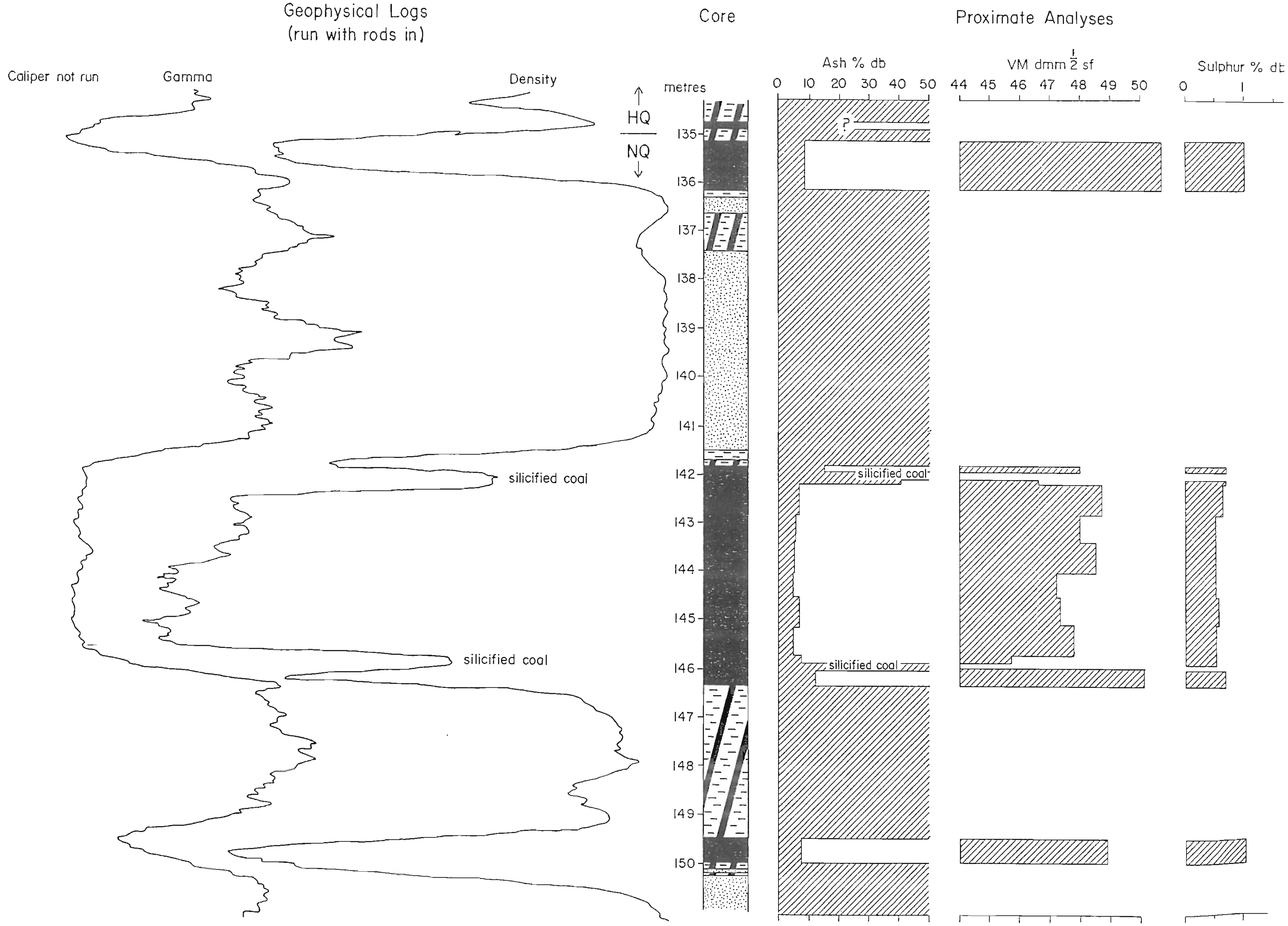


Figure 5.2: Gradational upper and lower contacts of the second seam in DH 118 (seams are numbered from the bottom up). Note the effect of silicification on the density log.

CLASSIFICATION OF DEPOSITS ACCORDING TO ASH CONTENT	
Up to 5 per cent	(Low)
5 to 10 per cent	(Medium)
10 to 15 per cent	(High)
15 to 20 per cent	(Very High)
From Bowen 1978	

Table 5.3: Classification of coals according to ash content (from Bowen, 1978).

Figure 5.3: Well preserved telocollinite interbedded with mineral matter-desmocollinite-liptodetrinite association (Sample 11859). [Field of view for all coal photomicrographs= 0.15x0.25mm].

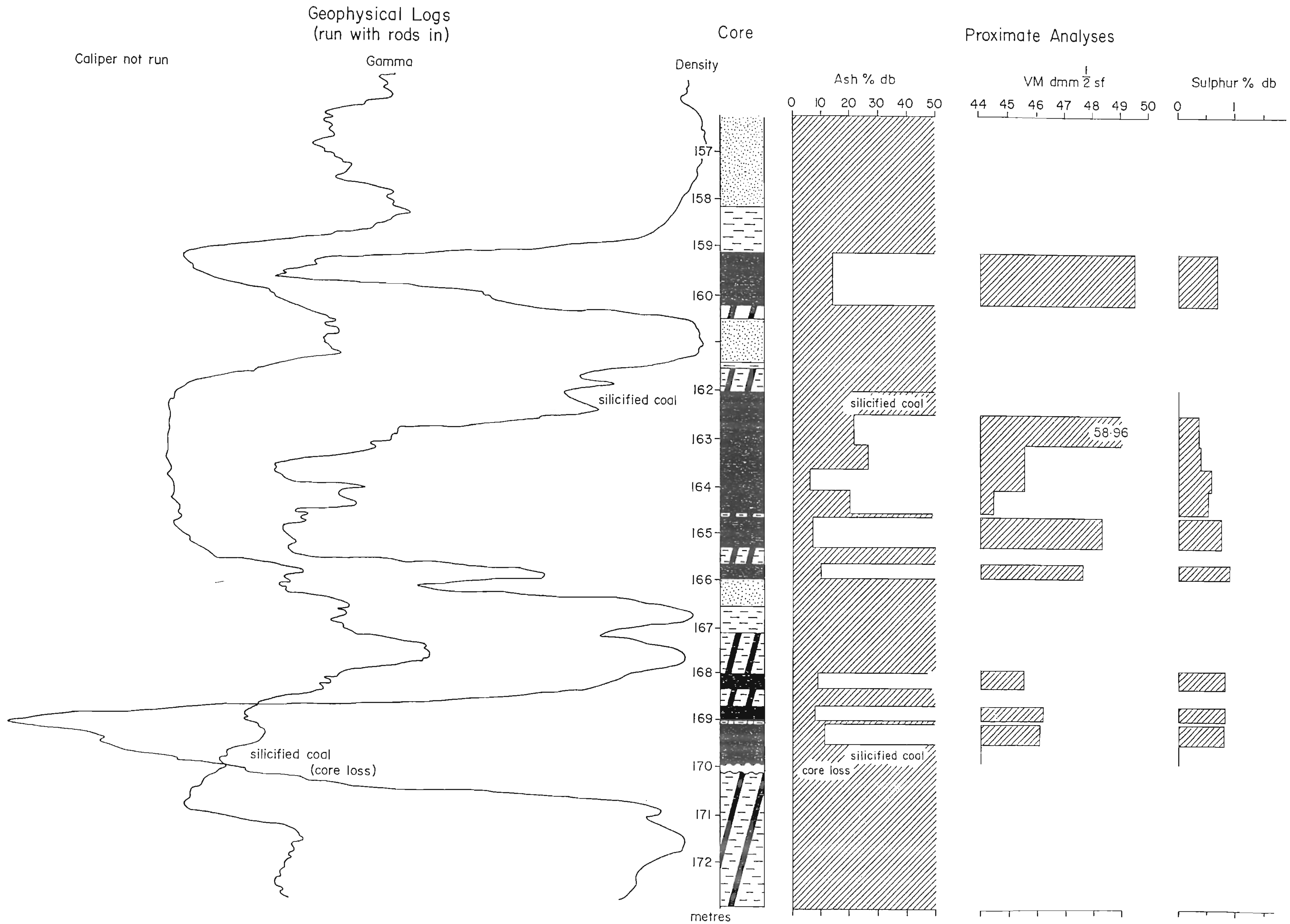


Figure 5.4: Variation in ash content in coal associated with clastic sedimentary partings. Basal seam, DH 118

ash content of coal associated with these partings results from a large component of detrital mineral matter, being dominated by quartz and kaolinite, commonly accompanied by muscovite.

The mineralogy of low ash coals (<5% dry basis) within the Rotokohu Coal Measures is dominated by occasional fine detrital quartz grains. In comparison, kaolinite is generally less common in LTA analyses of low ash coal, while petrographic analyses indicate that the clay minerals present are finely dispersed throughout the coal, not concentrated in discrete bands as in high ash coals. Some of the kaolinite detected in LTA analyses of low ash samples may be authigenic.

X-ray diffractograms of low ash coals commonly indicate gypsum. Low rank coals commonly contain substantial amounts of organically bound calcium (Francis 1971), which can combine with sulphur to form gypsum, due to either outcrop weathering, or during the LTA process (N. Newman pers. comm.). In medium to high ash samples, organically bound calcium is diluted by the increase in detrital minerals.

Smectite is locally present in the roof of the second seam (seams numbered from the bottom up) at Giles Creek, as mixed illite-smectite, associated with detrital kaolinite, muscovite, and quartz. This smectite is inferred to have probably formed in weakly acidic to neutral environments outside, or locally peripheral to the peat swamp. A humid subtropical environment such as that inferred to prevail during deposition of the coal measures (Mildenhall 1976) would have favoured smectite development (Dixon and Weed 1977). Smectite is inferred to have been washed into the peat swamp with detrital quartz, kaolinite, and muscovite, as peat deposition was replaced by clastic sedimentation.

5.2.2 Neo-formed Minerals

Neo-formed minerals refer to authigenic minerals which formed within the peat swamp. Feldspar is a common constituent of sandstone (visual estimation, Section 3.2) and carbonaceous mudstones/carbominerites (LTA analyses) within the Rotokohu Coal Measures, yet was not detected in any of the coal samples analysed. Feldspar must have been introduced into the peat swamps with detrital quartz and clay, hence the absence of feldspar from coal mineral matter suggests that this mineral was destroyed in the peat by humic acid solutions. Renton (1982) states that leaching by humic acids occurs during the process of humification, and persists from peat accumulation at the surface to early burial stages.

Strongly acidic swamp conditions are inconsistent with the predominantly marine influenced depositional environment suggested by maceral studies (Section 6.6). However, a marine influence does not necessarily imply a strongly alkaline environment of very high pH, as bacterial activity (the major cause of plant degradation in peat swamps) is most severe in swamp environments with pH levels between 4 and 7.5 (excluding other variables such as swamp oxygenation, Stach et al. 1982, p 33).

The presence of illite/muscovite in Rotokohu coals was attributed previously to detrital muscovite, and does not directly reflect low swamp pH conditions as is proposed for some illite/muscovite occurrences in overseas coals (Renton 1982). More work on the chemical environment of deposition in Rotokohu peat swamps, and on the general geochemical environment of the coal measure basin as a whole, is necessary to resolve the apparent conflict between an absence of feldspar and a brackish depositional environment.

Isolated fine blebs of kaolinite evident in some low ash samples are possibly neo-formed, or may represent flocculated clays (as a brackish depositional environment would favour flocculation, Newman J. 1986), although as stated previously, most kaolinite appears to be of detrital origin. Alkaline earth elements such as Ca, Na, and Mg probably occur as neo-formed, organically bound species in Rotokohu coals, although moderate to high ash samples may contain a proportion of these elements in detrital clay minerals. The presence of these elements in organically bound form is suggested by high temperature ash analyses of low ash coal (Section 5.5), and by the formation of gypsum in some LTA samples.

5.3 EPIGENETIC MINERALS

Epigenetic minerals are rare within Rotokohu coals, for which quartz, and iron sulphides (predominantly pyrite), are the only probable epigenetic minerals detected. Epigenetic carbonates were not detected in any of the samples studied.

5.3.1 Silicification within Rotokohu Coals

Silicified coal horizons are frequently observed in Rotokohu Coals. They are always lenticular in outcrop, and weather to a distinctive white colour (Figure 5.5). The lower boundary surface is commonly more gradational than the upper boundary surface, with compactional slickensides and quartz veining evident in some samples (Figure 5.6). These siliceous horizons are frequently associated with relatively high ash coal, being particularly common near the roof and floor of coal seams (Figure 5.7).

In fresh drill-core, siliceous horizons have a similar appearance to the enclosing coal, but with a slightly duller lustre. The high density of these horizons (relative to the enclosing coal) produces a distinctive gamma-gamma (density) geophysical log trace (Figures 5.2 and 5.4).

The ash content determined for 4 silicified horizons intersected in DH 118 varied from 69.3-80.3% db (ash content determined by CRA). X-ray diffraction of LTA residues reveals a mineralogy comprising solely of quartz (Appendix 9), and high temperature ash analyses are dominated by SiO_2 (>99.5%, Appendix 11).

Thin section, polished section and SEM investigations indicate that a significant proportion of the silica is fine grained, with coarsely crystalline detrital and authigenic quartz representing a smaller proportion of the total ash.

Polished sections of silicified coal are characterised by a sugary appearance, but with maceral textures still clearly visible (Figure 5.8). Both detrital and authigenic quartz are evident, although the amount of coarsely crystalline quartz observed is lower than the ash percentage deter-

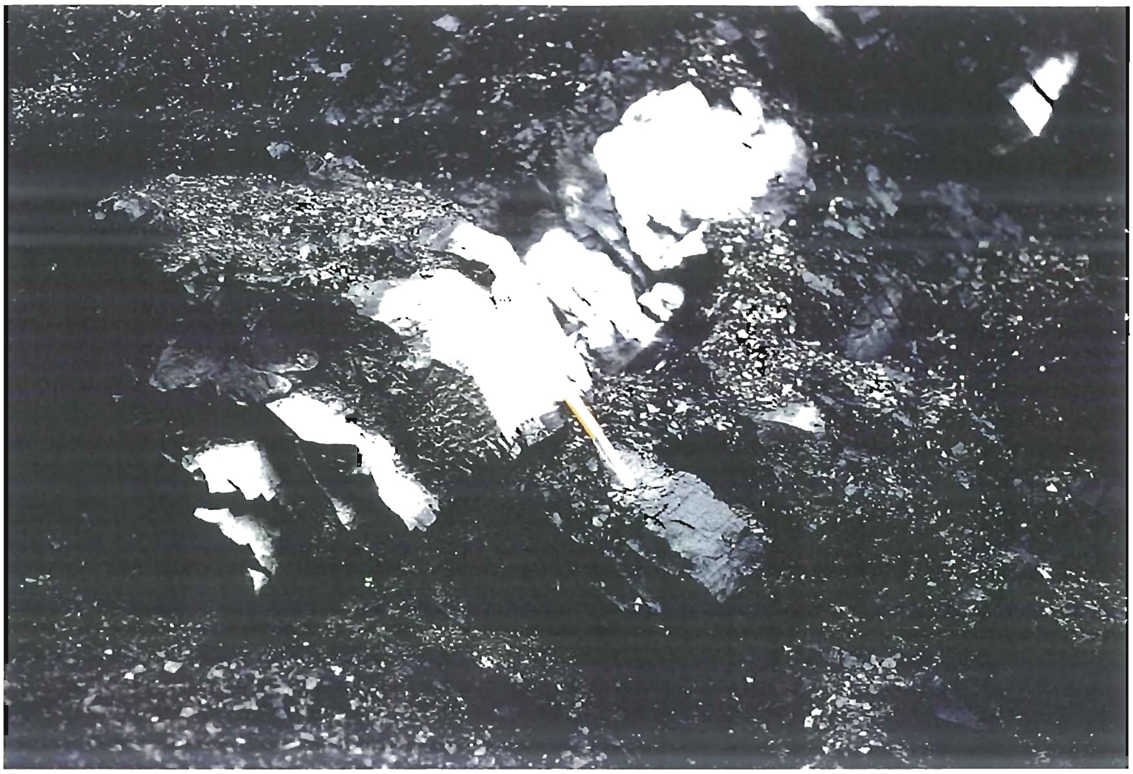


Figure 5.5: Close up view of silicified coal at Giles Creek Mine.

Figure 5.6: Quartz veining in silicified coal (Sample 11881).

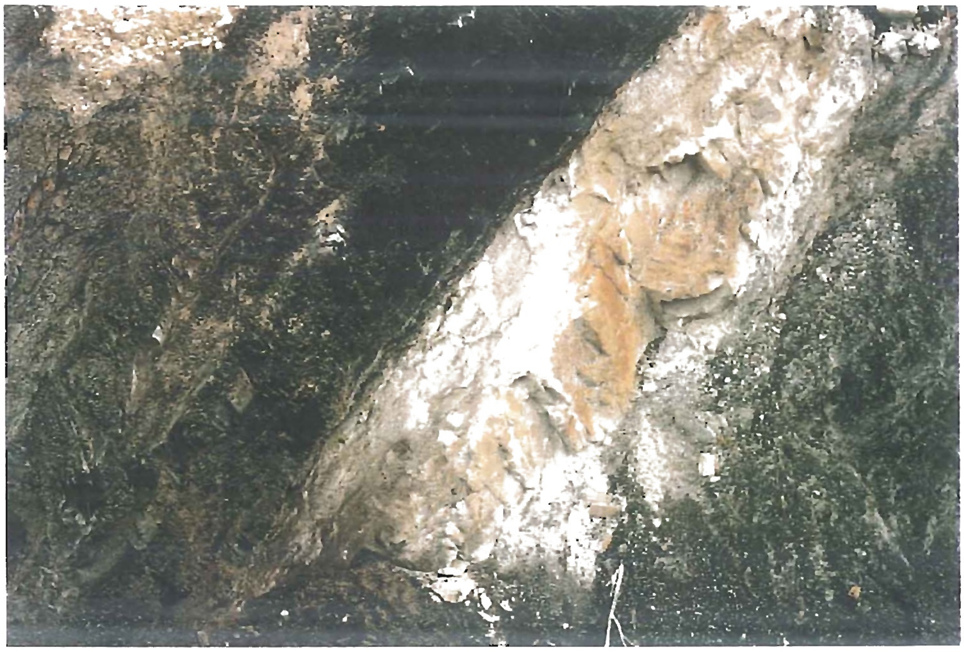


Figure 5.7: Silicified coal horizons associated with crevasse-splay sandstone and mudstone partings at Giles Creek Mine. For scale, the sandstone horizon is approximately one metre thick.

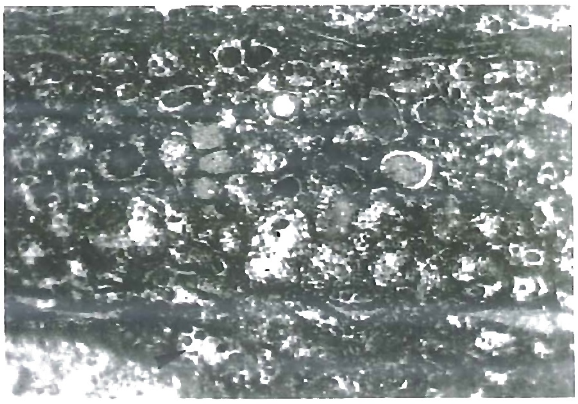


Figure 5.8: Polished section (oil immersion) of silicified coal, showing "sugary" appearance. Small quartz crystals are evident in some cell cavities (arrowed) [Sample 118844].

mined in proximate analyses (30-40 % of the total sample, or about one half of the sample in most visual estimates). In thin sections of silicified coal, coarsely crystalline quartz is seen to be generally restricted to cell infillings within root/stem cross-sections, occasional bedding parallel bands and cross-cutting veinlets (Figure 5.9).

SEM investigations show good preservation of the original maceral textures by fine grained silica (Figures 5.10 and 5.11). Large, subhedral quartz crystals commonly infill cell cavities, while aggregates of fine euhedral quartz crystals infill small fissures and veinlets (Figures 5.12 and 5.13).

The coal sample overlying silicified coal at Giles Creek (sample 11812) contains a relatively high percentage of fine sub rounded detrital quartz grains, concentrated in quartz rich layers (7% of the total petrographic count for this sample, Figure 5.14). Fine haloes of mineral matter (probably quartz) were observed set back from the grain margin of some quartz grains, while coarse grained quartz overgrowths were observed during SEM investigations on the margins of some macerals within siliceous partings.

Siliceous beds within Rotokohu coals are interpreted as a low temperature, early diagenetic alteration of coal horizons which were initially rich in detrital quartz. Features consistent with a detrital origin of the silica include:

a) the presence of abundant detrital quartz grains within silicified horizons, and in coal immediately enclosing these horizons,
b) their lenticular geometry, and
c) the vertical and lateral field association with high ash horizons and clastic partings.

Fairbridge (1967, p71) suggests a late anadiagenetic stage with rising waters of high pH would favour silicification within coal. This origin cannot be invoked for Rotokohu coals, as their rank is too low to postulate deep burial (Section 6.7). Furthermore, compactional slickensides and minor compaction of cell cavities suggest silicification occurred during early diagenesis, shortly after humification-

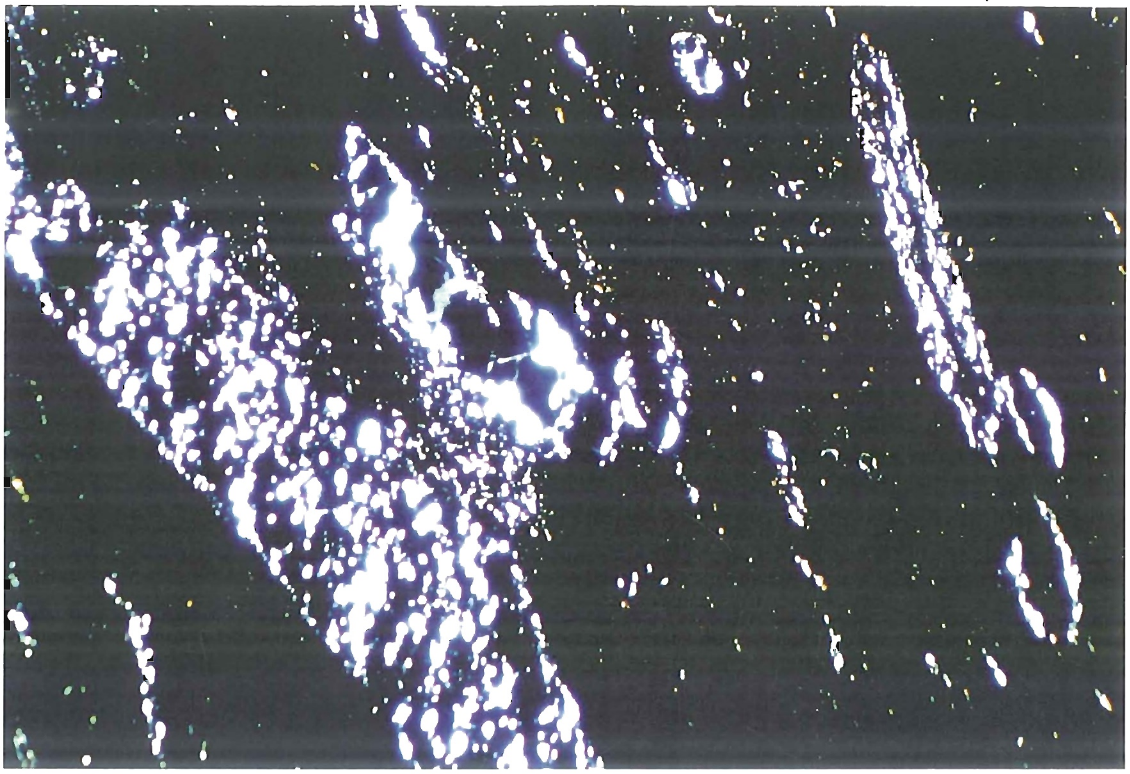


Figure 5.9: Cross-polars view of silicified coal. Coarsely crystalline quartz preferentially infilling stem/root cross-sections. The dark background is replaced by finely crystalline quartz (Sample 1184, x105).

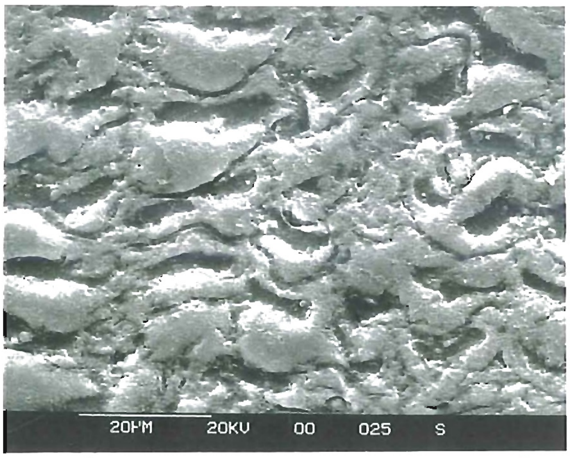


Figure 5.10: Good preservation of cell wall material (telinite) by fine grained silica. Cell cavities show minor compaction (Sample 11884).

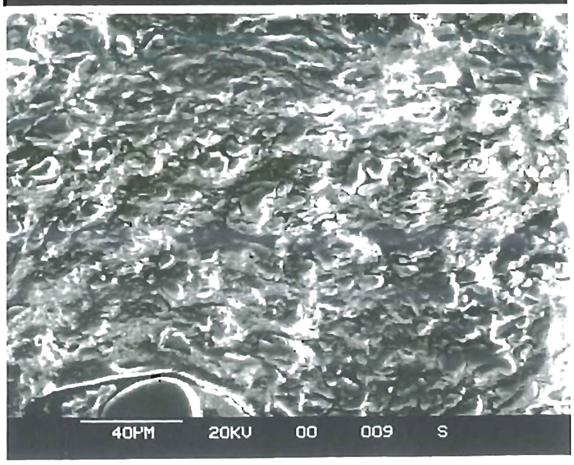


Figure 5.11: General view of silicified desmocollinite-rich groundmass (Sample 11884).

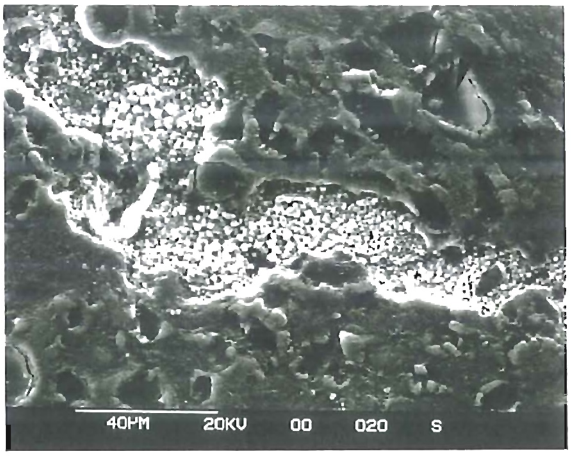


Figure 5.12: Quartz vein within sample 11884. Large quartz crystals (?) present in surrounding material (arrowed).

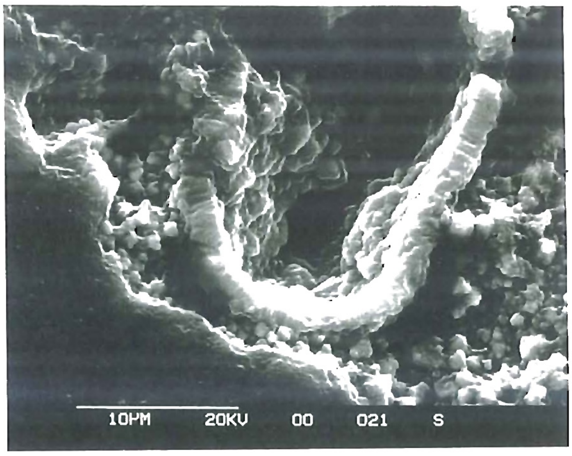


Figure 5.13: Close-up of euhedral quartz crystals and minor recrystalisation within quartz vein (Figure 5.12), Sample 11884.

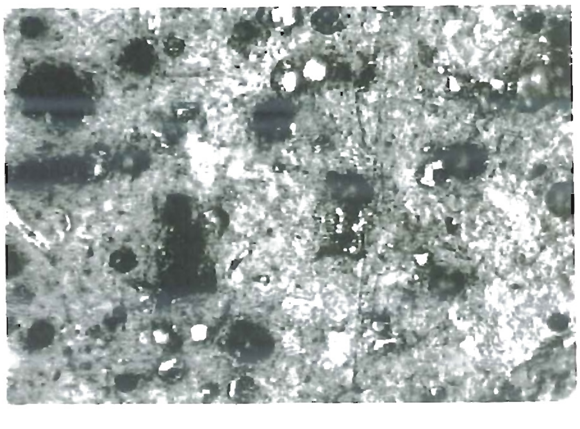


Figure 5.14: Detrital quartz grains within coal sample 11812, overlying a silicified coal horizon (Sample 11812).

gelification produced the maceral textures still evident in polished sections.

An occurrence of euhedral quartz crystals in low rank Brunner coal at Charleston has been considered to result from low temperature (30-90^{0}C) crystallisation from silica-rich solutions during early burial (Soong and Blattner 1986), and is probably a good analogue for the more widespread, relatively finer grained silicification observed in Rotokohu coal.

The pH of peat rapidly rises during shallow burial (Waksman and Stevens 1929). The presence of early authigenic carbonate minerals in some West Coast coals is strong evidence for a high pH during early burial and diagenesis in some coals (Newman N. pers. comm.), and such conditions are proposed for the silicification of Rotokohu coals.

Although relatively common in Rotokohu coals, silicification is rare within West Coast coals in general (Newman N. pers. comm.), and may in part reflect the relatively unusual geochemical and geological history of the "Rotokohu" basin. Conditions necessary for silicification within Rotokohu coals were achieved only locally, where abundant detrital quartz was present.

The presence of this detrital quartz appears to have induced local supersaturation of the interstitial fluid during early diagenesis. The silica saturated waters surrounding the quartz grains would have been free to migrate short distances between the relatively permeable peat/lignite macerals which enclosed the detrital quartz. This relatively good permeability favoured the infilling of interstices within root/stem cross sections, and some telinite lenses by relatively coarsely crystalline quartz, while allowing the structural detail of the desmocollinite dominated groundmass to be faithfully duplicated by fine grained silica.

Exinite macerals appear to resist the silicification process, while veinlets infilled with euhedral quartz crystals are interpreted as representing a late phase of silicification. Continued burial of the peat probably induced microfracturing of the relatively brittle partially silicified coal, followed by infilling of these fractures with coarsely crystalline quartz derived from the immediately surrounding area.

5.4 SULPHUR

5.4.1 Introduction

Pyrite is by far the most abundant iron sulphide detected in both LTA and petrographic analyses, with marcasite only detected in sample 11872 (Appendix 9). All sulphur values referred to in the text were determined by CRA on a weight percentage basis, and are tabulated together with proximate analyses in Appendix 8. Forms of sulphur (i.e. organic vs inorganic) have not been determined for any Rotokohu coals, although an estimation of the pyritic sulphur content is attempted in Section 5.5.

5.4.2 Distribution

Sulphur distribution within the Rotokohu Coal Measures is strongly influenced by stratigraphic position (Figure 5.15). Coals from the Thomson Member have medium to high sulphur contents (>1.1% db, sulphur classification as proposed by Bowen 1978, p16). High sulphur coals (>2.5% db) within the Thomson Member occur in sections with frequently interbedded bioturbated sandstone (lithofacies Bs, Mft and Bz, Section 3.3). Medium sulphur coals (1.1-2.5% db) within the Thomson Member occur in multiseam sections without frequently interbedded bioturbated sandstone (e.g. upper Rough Creek).

Coals from the lower Camp Member commonly have low sulphur contents (<1.1% db). Medium to high sulphur contents occur locally in the upper Camp Member near the unconformity with the Giles Formation, while very high sulphur contents occur where coal seams are overlain by thick, porous conglomerate horizons.

Similar influences of roof lithology on sulphur content have been noted by Horne et al. (1978) and Newman J. (1985 and 1986), where porous roof lithologies have allowed secondary

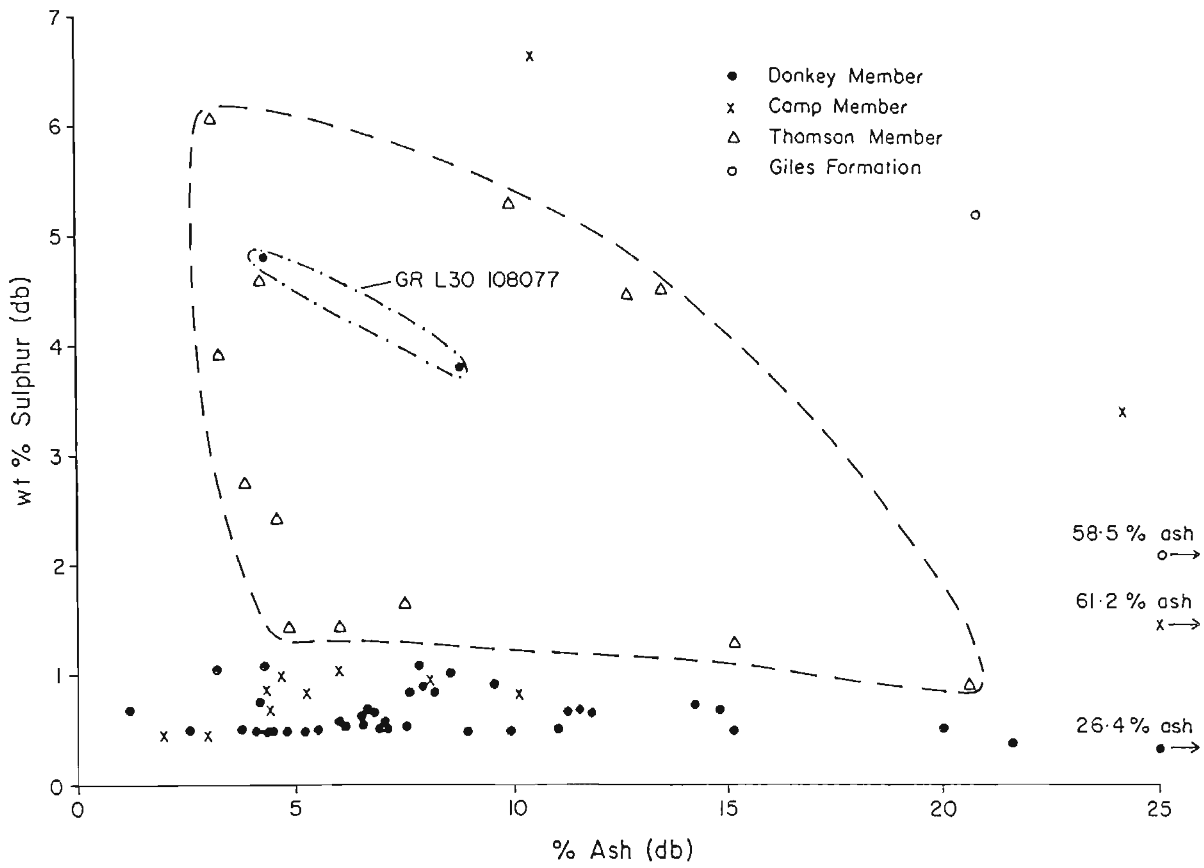


Figure 5.15: Distribution of sulphur in Rotokohu and Giles Formation coals.

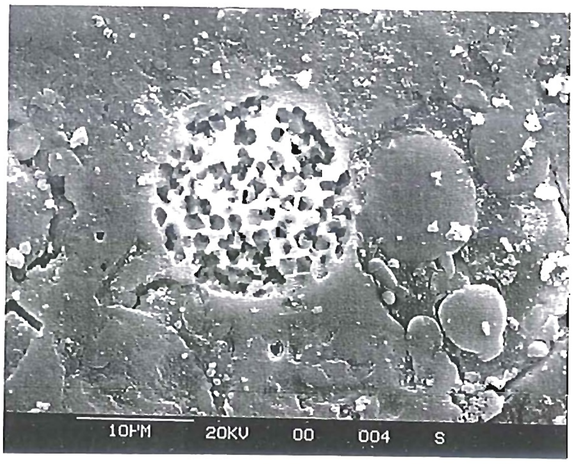


Figure 5.16: Framboidal pyrite "ghost" (Sample 11884). Pyrite has been removed by the preparation process, leaving behind the outline of the frambiod.

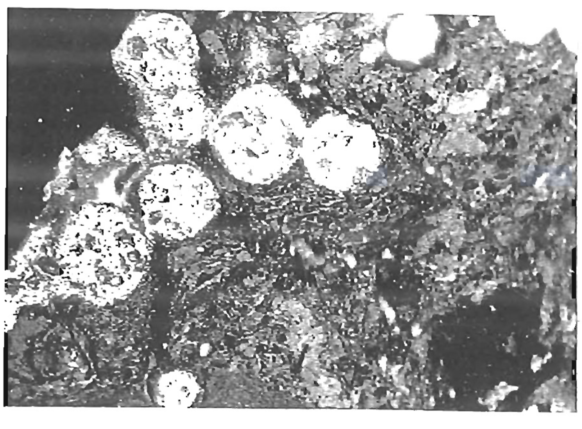


Figure 5.17: Syngenetic to late syngenetic, pyrite concretions with limited compaction (Sample 11856).

enrichment from permeating marine influenced solutions. In the upper Camp Member these solutions are inferred to have resulted from the regional transgression which terminated deposition of the Rotokohu Coal Measures and led to deposition of the shallow marine Giles Formation in the northern Inangahua Valley.

Coal from the Donkey Member is nearly always low sulphur, with the only exception occurring near Giles Creek Mine (GR. L30 108077). At this locality, shallow marine sediments of the Giles Formation unconformably overlie the basal seam of the Donkey Member, producing locally high sulphur coal (3.8-4.8% sulphur db, Figure 6.14).

Two samples analysed from the Giles Formation at Giles Creek also have high sulphur contents (2.1 and 5.2% sulphur db respectively, samples 11838 and 11859), with the interbedded shallow marine sediments the likely source for this high sulphur.

5.4.3 Forms of Pyrite

Framboidal pyrite (small concretions consisting of a mass of individual cubic or octahedral crystallites, Figure 5.16) is extremely common within the vitrinite of coals from the Thomson Member and the Giles Formation. Framboids were also occasionally observed within coal from the upper Camp and Donkey Members, and within the lower Donkey Member. These pyrite framboids commonly produce compactional features in the surrounding vitrinite, and are inferred to probably be of syngenetic origin.

Horne et al. (1978) suggest that framboidal pyrite is produced by sulphur-reducing microbial organisms found in marine to brackish waters, and that high concentrations of framboidal pyrite are formed where marshes have been transgressed by marine to brackish-water environments. The high concentrations of framboidal pyrite present in coal samples from the brackish/marginal marine influenced Thomson Member and Giles Formation, are consistent with the origin for framboids proposed by Horne et al. (1978).

Irregular-shaped pyrite replacing vitrinite macerals, and pyrite veinlets are observed within high sulphur coals. These pyrite occurrences are commonly considered to be epigenetic (Horne et al. 1978, Renton 1982), but may also be a late syngenetic (i.e. soft brown coal) phase, as faint compaction is sometimes evident in the surrounding vitrinite. Fine amorphous concretions commonly observed in high sulphur coals also appear to represent syngenetic to late syngenetic forms of pyrite (Figure 5.17). However since some compaction continues throughout the brown coal stage, the distinction between syn- or post-depositional pyrite on the basis of petrographic criteria is somewhat ambiguous within low rank coals such as Rotokohu coals.

The strong stratigraphic control on sulphur discussed previously suggests that much of the sulphur in the Thomson Member and Giles Formation is either syn-depositional or immediately post-depositional. The generally low sulphur content of the marine influenced basal seam of the Donkey Member suggests that the high sulphur content in Thomson Member and Giles Formation coals probably results from autocyclic transgressive phases (Section 3.3) producing an "immediate" post-depositional sulphur enrichment. Local occurrences of high sulphur values in the Camp and Donkey Members are inferred to represent relatively late post-depositional secondary enrichment from percolating marine influenced solutions derived from the largely shallow marine Giles Formation.

5.5 HIGH TEMPERATURE ASH CHEMISTRY

SiO_2 dominates the major element chemistry of most samples analysed (Appendix 11). A plot of SiO_2 (weight percentage) versus ash percentage (db) reveals a broad positive relationship (Figure 5.18), SiO_2 generally increasing with increasing ash. This trend is however complicated by two factors discussed previously:

a) highly siliceous coal horizons, and
b) the tendency for the detrital mineralogy to become more diverse with increasing ash.

As a result, low ash samples associated with siliceous partings can contain anomalously high SiO_2 percentages (e.g. samples 11812 and 11872), while the high ash coals and carbonaceous mudstones/carbominerites analysed never attained such high SiO_2 contents (always <85% SiO_2), presumably because the silica is diluted by the constituents of other minerals detected by XRD investigations.

Similar trends are evident in a plot of Al_2O_3 versus ash percentage (Figure 5.19), where there is a broad positive trend of increasing Al_2O_3 with increasing ash for most samples. However, the very high ash sample (11838) has a slightly lower Al_2O_3 percentage than samples dominated by clay minerals (samples 11823 and 11855), reflecting the greater variety of minerals present in this sample. Samples associated with silicified horizons commonly have anomalously low Al_2O_3 values, reflecting an absence of minerals other than silica.

A plot of SiO2 versus Al_2O_3 for all high temperature ash samples clearly displays the controls on high temperature ash chemistry discussed above (Figure 5.20). A low Al_2O_3/high SiO_2 field results from those samples associated with siliceous partings. A clay rich field, with an SiO_2:Al_2O_3 ratio slightly above 2:1, includes moderate to high ash samples containing detrital quartz, kaolinite and muscovite.

Sample 11861 has the same SiO_2:Al_2O_3 ratio as kaolinite (9:8), but X-ray diffraction only detected quartz, suggesting a dominance of organically bound mineral matter in this low ash sample. Sample 11826 has an anomalously low SiO_2:Al_2O_3 ratio, substantially below that of kaolinite. X-ray diffraction of this low ash sample revealed quartz, kaolinite, gypsum and pyrite. Aluminium hydroxides, as described by Newman N. (1985) from other West Coast coals, were not detected; consequently much of the alumina in this coal is inferred to be complexed with humic material.

K_2O and TiO_2 contents are closely related to the occurrence of clay minerals. Plots of K_2O and TiO_2 versus ash percentage show broad positive correlations (Figures 5.21 and 5.22). High K_2O content is clearly related to the presence of muscovite and/or illite. Moderate to high ash samples commonly contain muscovite (Section 5.3), and consequently have high $K_2O:Al_2O_3$ ratios (Figure 5.23). Moderate to high ash samples with very low K_2O contents correspond to quartz rich, or possibly quartz/kaolinite rich plies, whereas all low ash samples have very low K_2O contents. Most clay rich samples have high $TiO_2:Al_2O_3$ ratios (Figure 5.24), suggesting most of the TiO_2 is bound in clay minerals.

CaO and MgO both show relatively strong negative correlations with ash percentage (Figures 5.25 and 5.26). Because no carbonate minerals have been detected, it is assumed that most MgO and CaO will be either organically bound, or occur in detrital minerals. The controls on Na_2O in Rotokohu coal ash is less clear than for other alkali earth elements (Figure 5.27). Na_2O levels are commonly low (<0.5%), but four samples with relatively high Na_2O contents are identified.

An inverse relationship between the ash constituents MgO, CaO, and Na_2O, and ash usually reflects the strong organic character of these elements, with increasing detrital mineral matter diluting the organically bound component. Plots of alkali: 1/ash%(db) compensate for the diluting effect of detrital mineral matter. A strongly organic character (i.e. an intimate association of mineral matter and coal) is indicated by a positive correlation, with little deviation from a "best fit line", passing through 0.01 1/ash% if the element is entirely organically bound (Newman N. pers. comm.).

A plot of MgO against 1/ash%(db) indicates a strong positive correlation, suggesting that MgO is primarily organically bound (Figure 5.28). However, three small groups show a noticeable deviation from the "best fit line".

a) High ash samples which plot above the line all contain muscovite, in which some MgO is inferred to be bound.
b) Samples associated with siliceous partings have anomalously low MgO contents, partly attributable to an

absence of minerals other than silica.

c) The very high MgO value for low ash sample 11864 is interpreted as probably resulting through "contamination" by epigenetic material from the local overthrusting of marine sediments. Anomalous sample 11826 was noted previously as being peraluminous, and may contain an unusually high concentration of organically bound alkali.

A plot of CaO against 1/ash%(db) (Figure 5.29) reveals similar trends to MgO, with samples associated with siliceous partings having anomalously low CaO contents, while samples containing fresh muscovite and feldspar have anomalously high CaO contents. However, although a broad positive trend is suggested by the majority of samples, they do not plot on a single straight line. The deviation from a single "best fit line" suggests there are a number of controls other than a simple organic association. The affect of weathering is probably a major cause of some of this variation, although other probable influences include;

a) variations in coal type, and
b) possible epigenetic carbonates, as yet undetected in Rotokohu coal,

A plot of Na_2O against 1/ash%(db) (Figure 5.30) reveals a complicated distribution with no obvious single trend. High Na_2O contents occur in samples associated with muscovite and feldspar, and in the peraluminous sample (11826), while coals associated with siliceous partings have anomalously low Na_2O contents. The remainder of the samples show a very poor, possible low gradient positive correlation, but more work is obviously necessary to determine the controls on Na_2O in Rotokohu coals.

The distribution of Fe_2O_3 within Rotokohu coals appears to be relatively complicated, and requires more investigation, particularly with respect to the ratio of inorganic to organic sulphur. A plot of sulphur versus "Fe_2O_3(ash) in coal %" (where Fe_2O_3(ash) in coal %=[Fe_2O_3 in ash/100] x Ash% db), reveals a relatively good positive correlation (Figure 5.31).

The solid line is the theoretical ratio corresponding to pyrite, if all Fe_2O_3 and sulphur were to occur only in pyrite. All samples analysed plot in a linear field on the sulphur-rich side of this line, suggesting that approximately 20-25% of total sulphur in Rotokohu coals is pyritic, assuming pyrite to be the major iron mineral in unweathered coal. Major deviation from the "best fit line" (dotted line) may result from the effects of outcrop weathering. Variations in iron content due to differences in ash mineralogy are probably a minor control, as iron rich clays such as chlorite have not been detected in Rotokohu coals. However some iron will be present in muscovite, and some may be complexed in organic material.

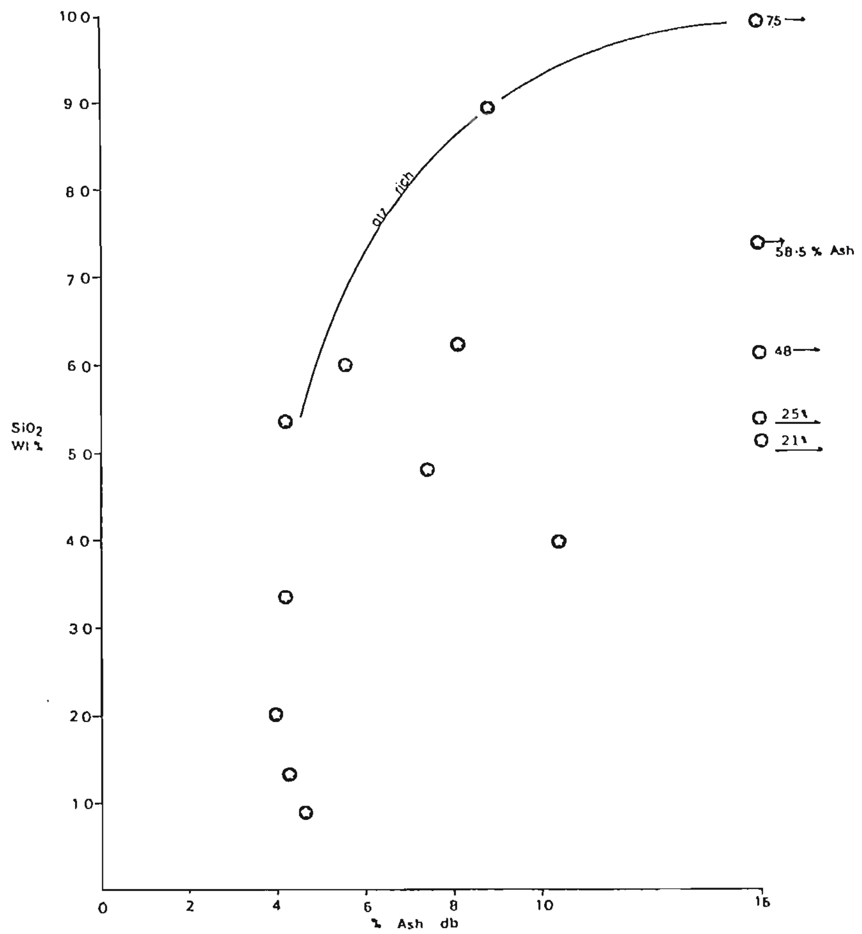


Figure 5.18: Broad positive relationship between SiO_2 and ash percentage. Siliceous horizons produce extremely quartz rich samples.

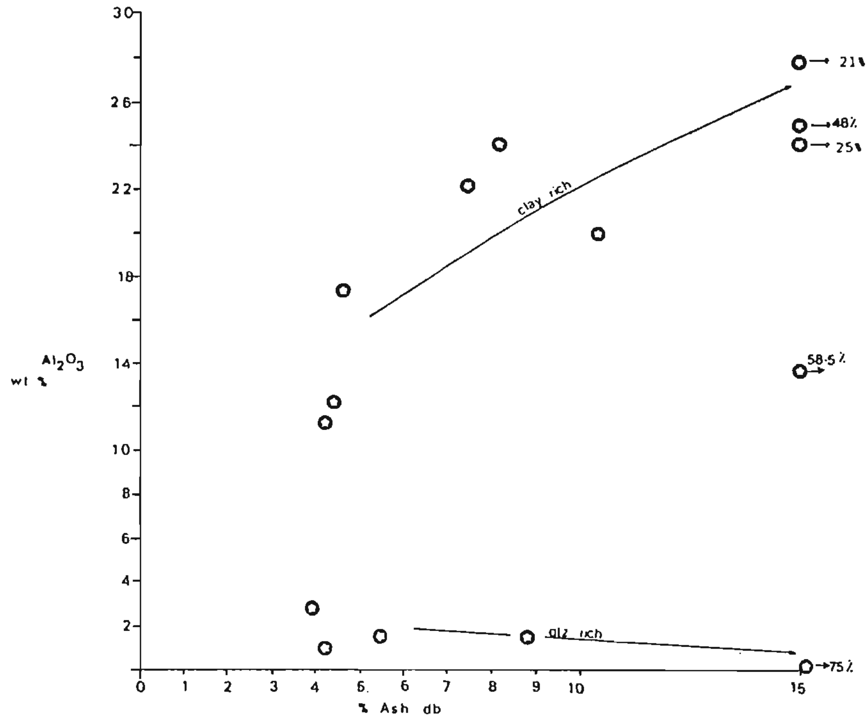


Figure 5.19: Relationship between Al_2O_3 and percentage ash.

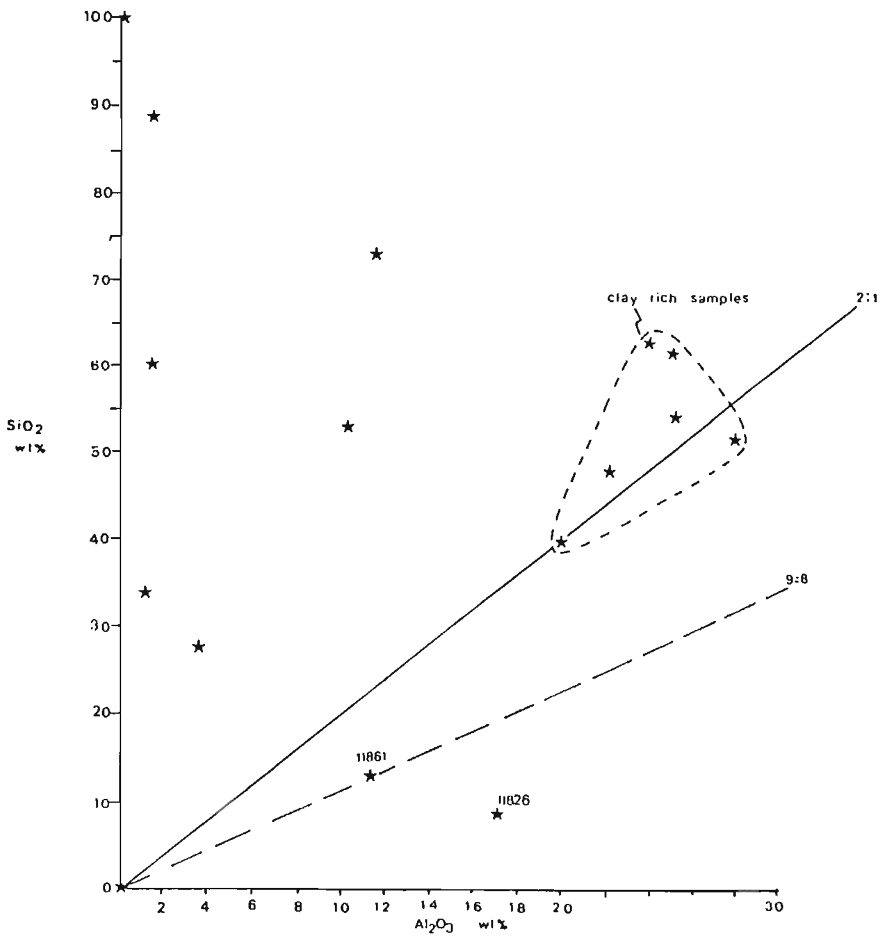


Figure 5.20: Plot of SiO_2 versus Al_2O_3. The 9:8 ratio is the approximate ratio of SiO_2 to Al_2O_3 in kaolinite.

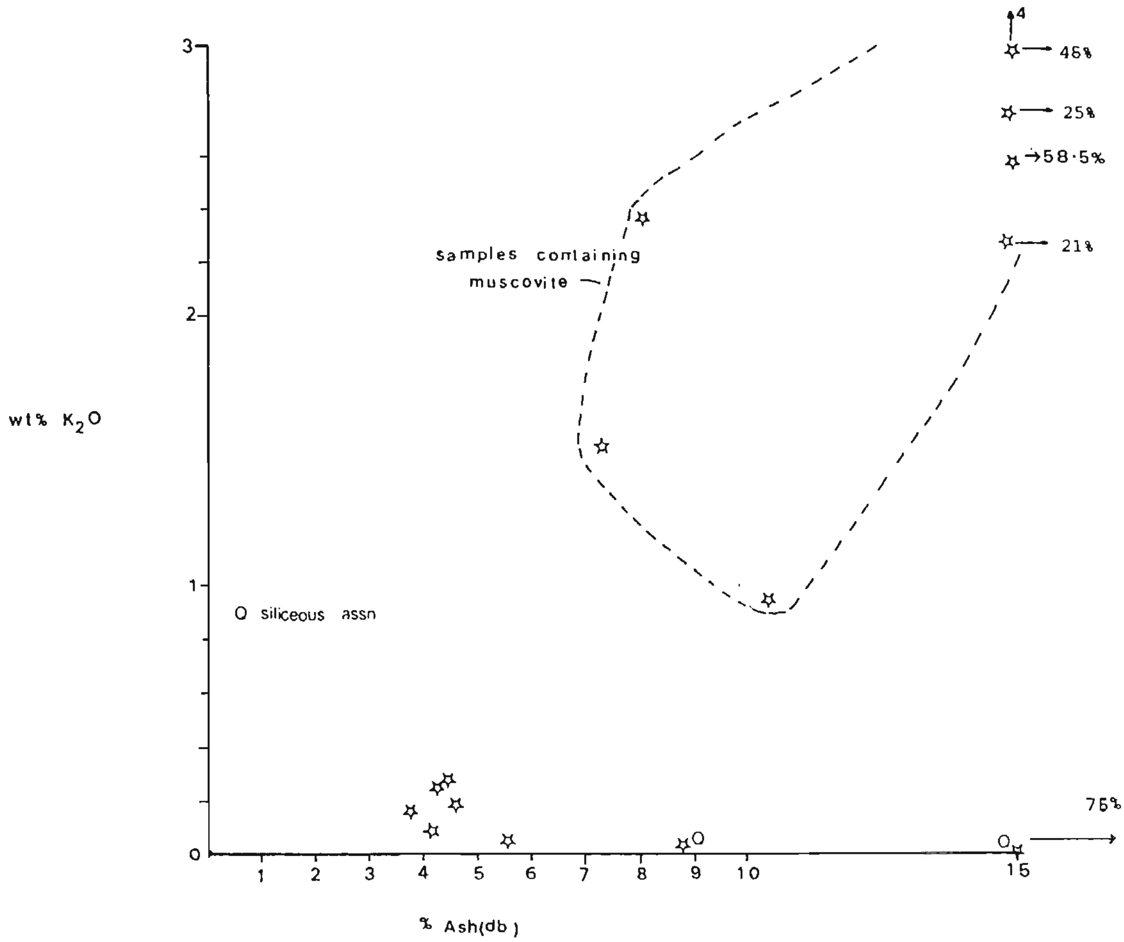


Figure 5.21: Plot of K_2O versus ash percentage.

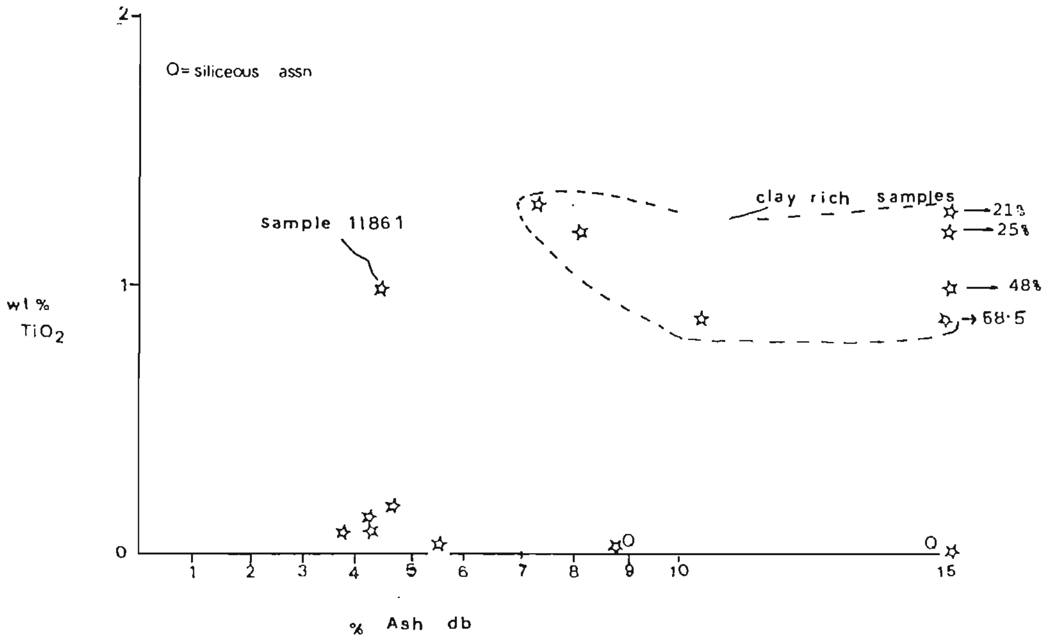


Figure 5.22: Plot of TiO_2 versus ash percentage.

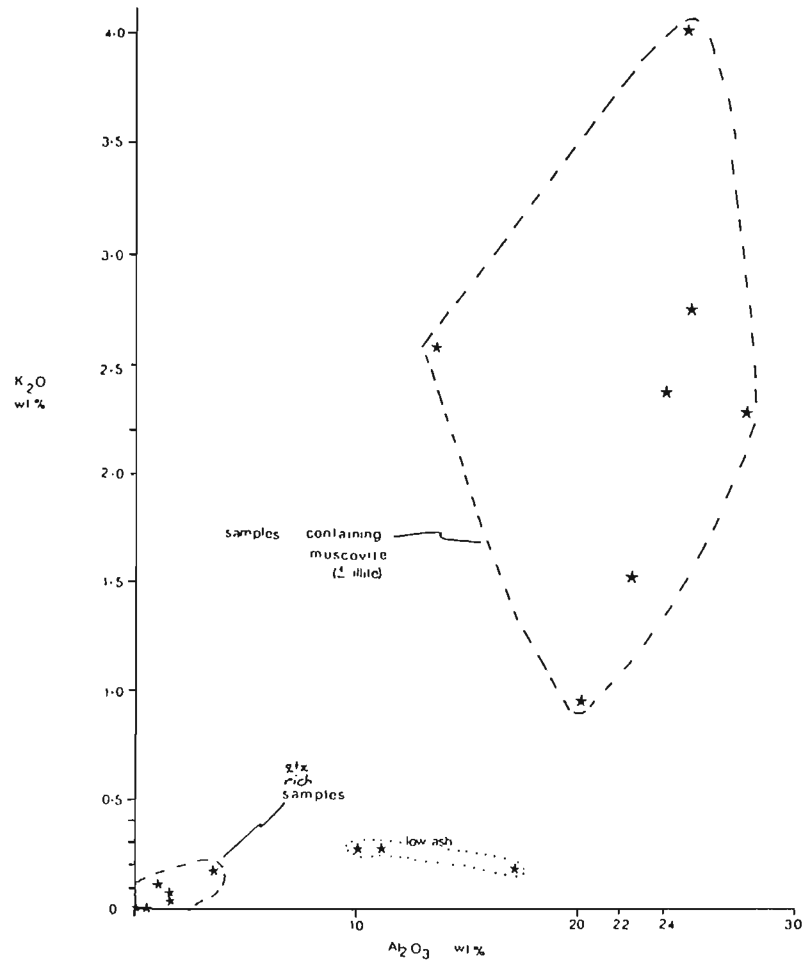


Figure 5.23: Plot of K_2O versus Al_2O_3 percentage.

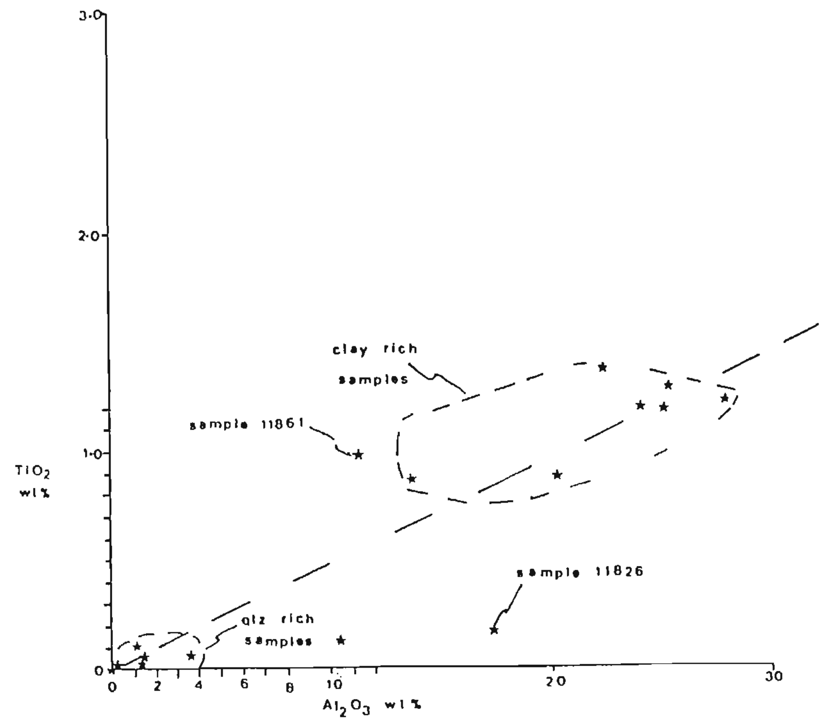


Figure 5.24: Plot of TiO_2 versus Al_2O_3.

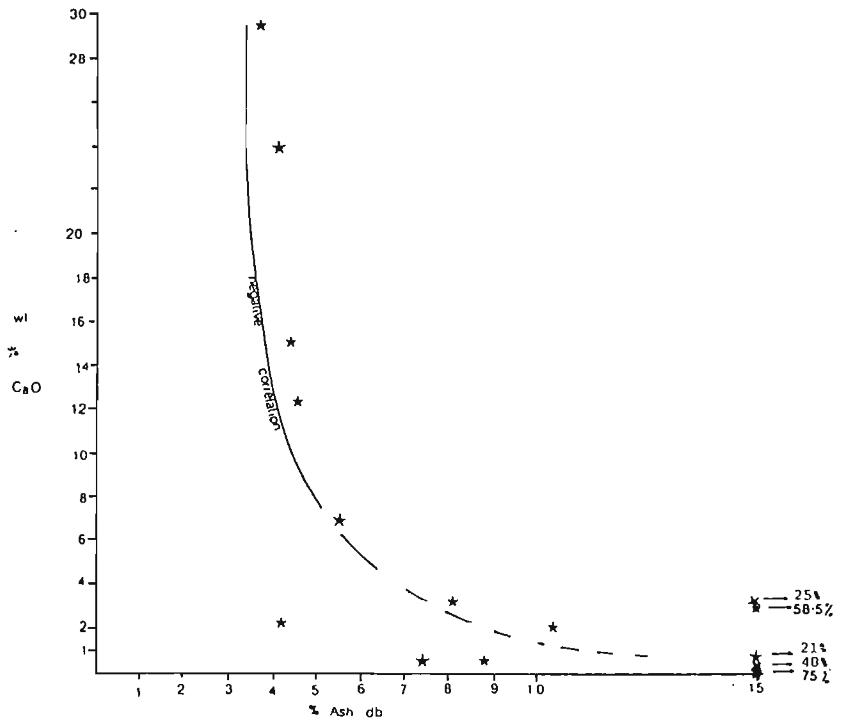


Figure 5.25: Plot of CaO versus ash percentage. A broad negative correlation is present.

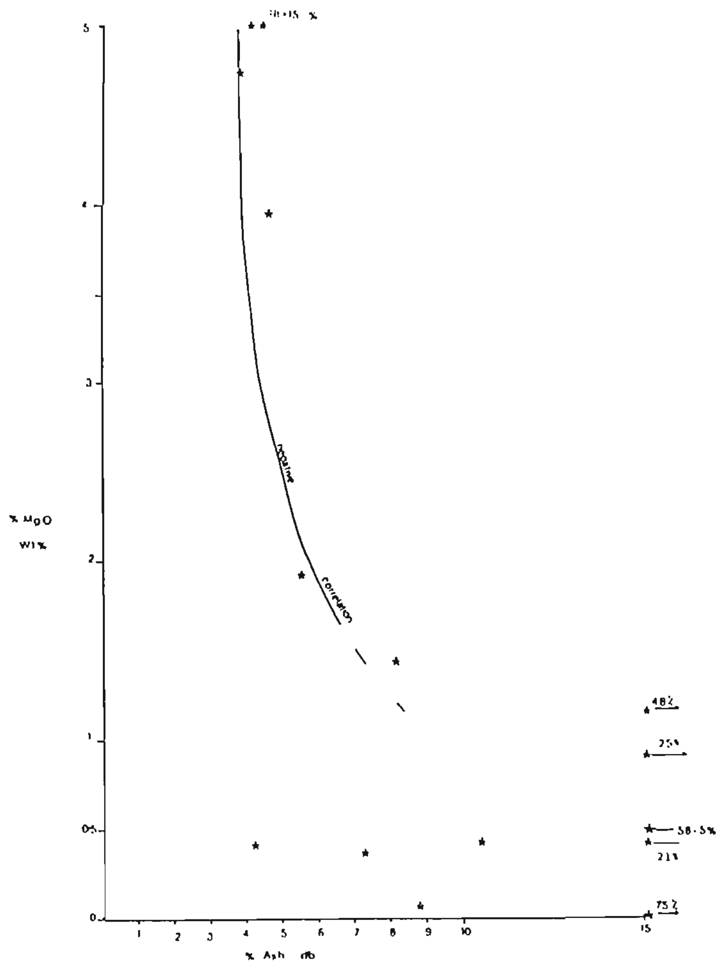


Figure 5.26: Plot of MgO versus ash percentage. A broad negative correlation is present.

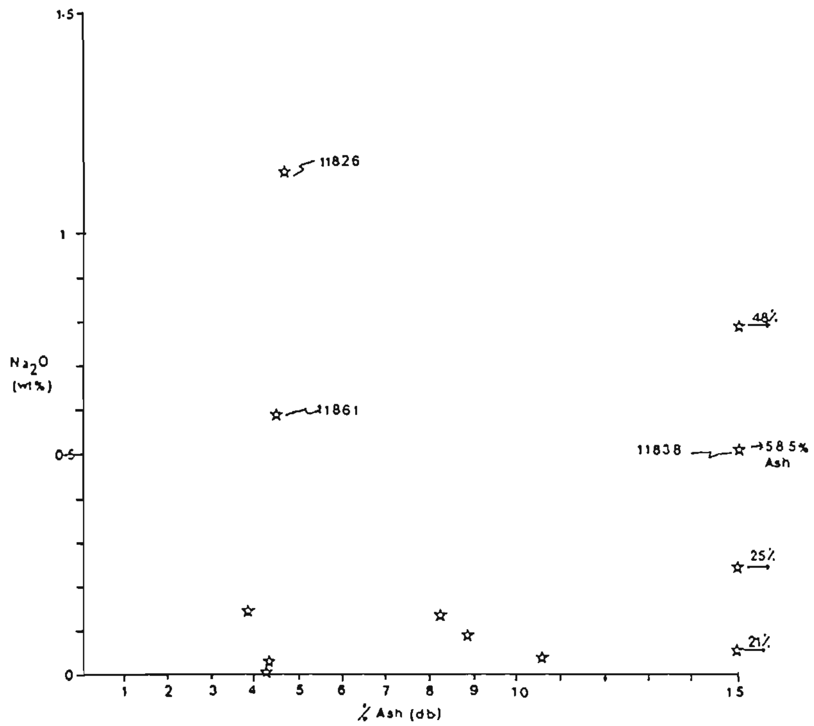


Figure 5.27: Plot of Na_2O versus ash percentage. No obvious correlation.

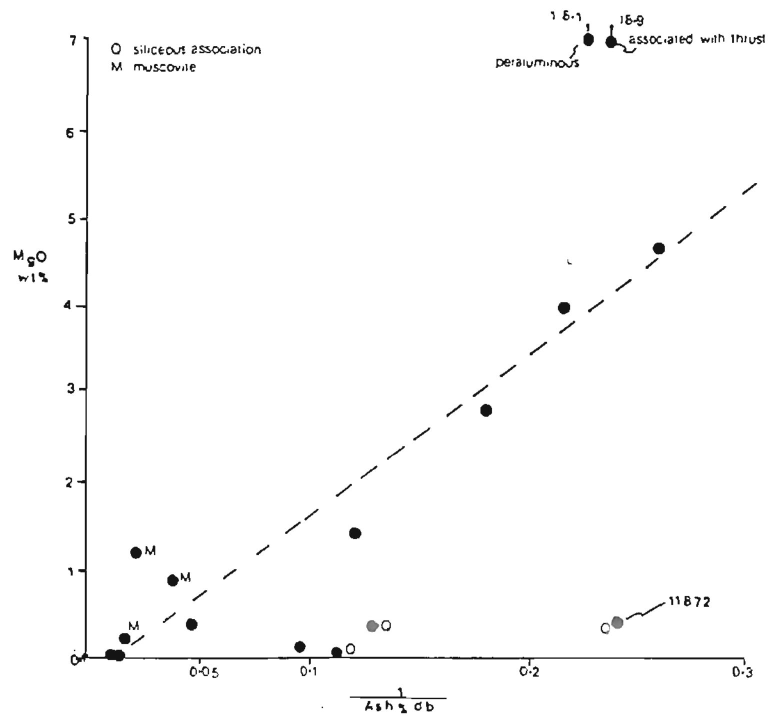


Figure 5.28: Plot of MgO versus 1/Ash% db.

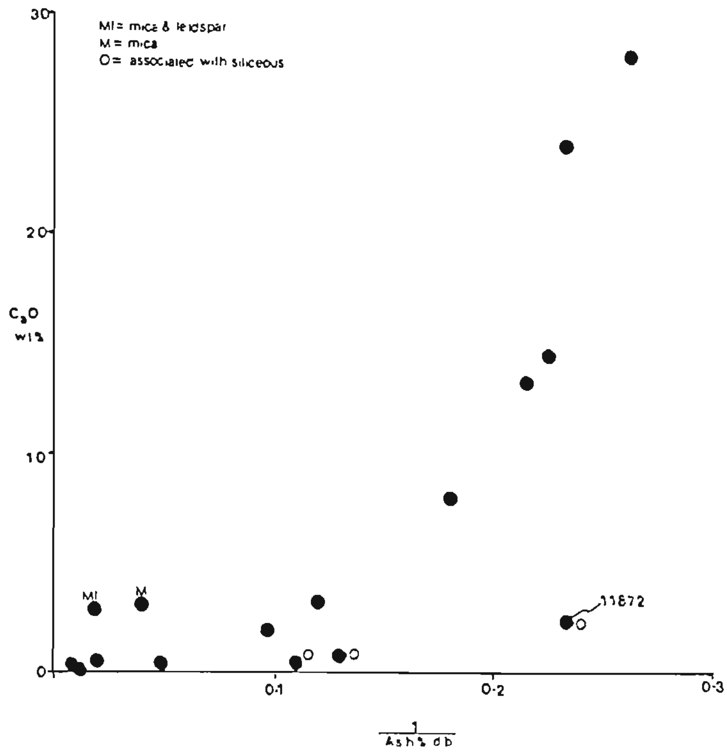


Figure 5.29: Plot of CaO versus 1/Ash% db.

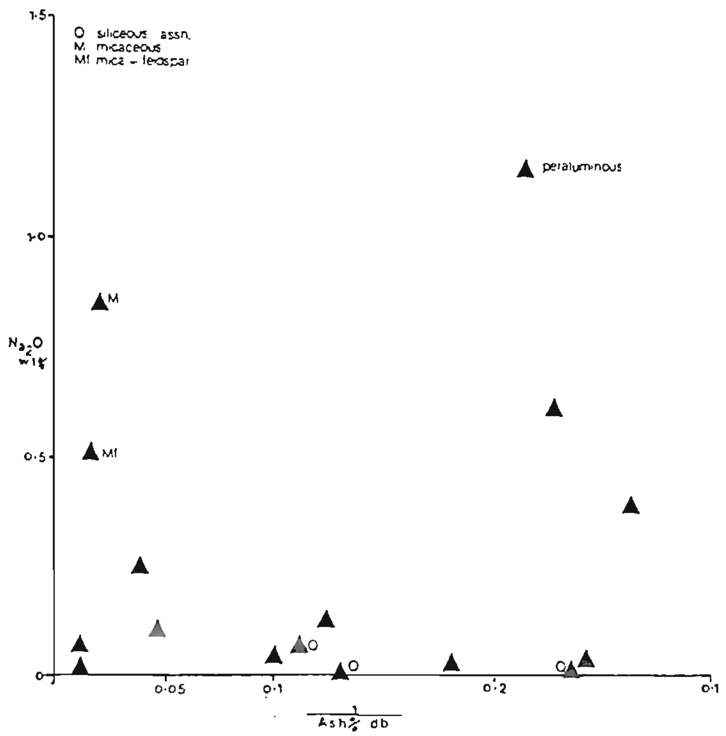


Figure 5.30: Plot of Na_2O versus 1/Ash% db.

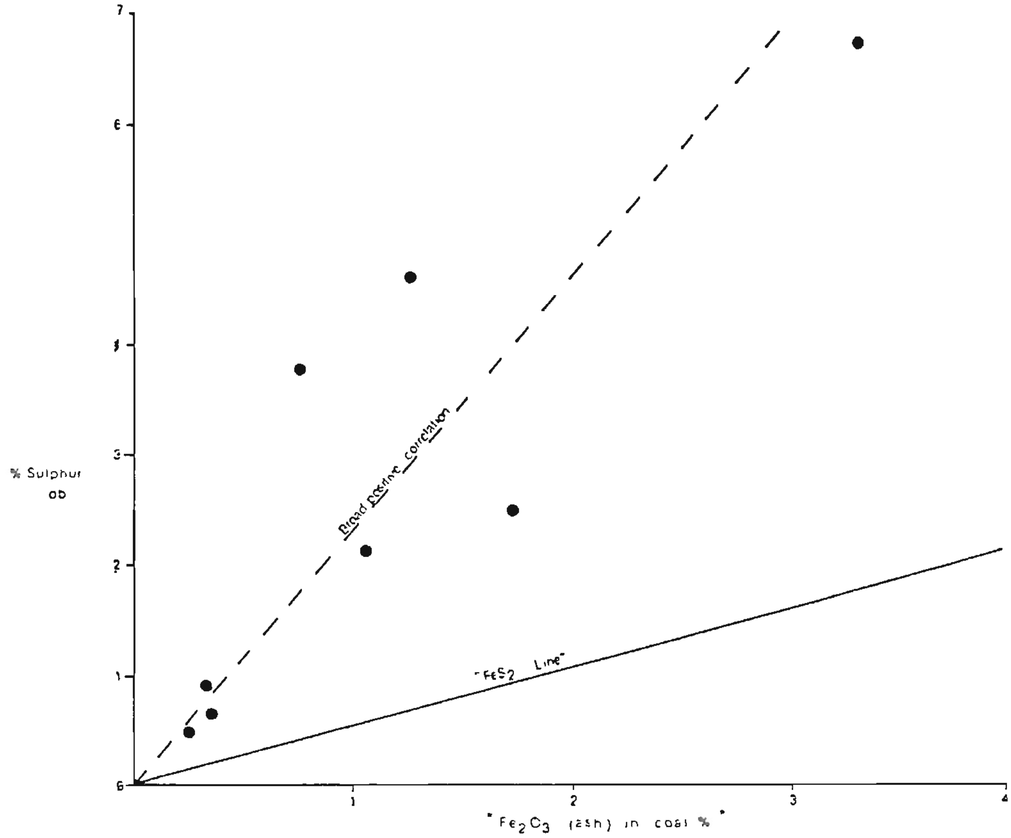


Figure 5.31: Plot of Fe_2O_3 (ash) in coal % versus percentage sulphur. Broad positive correlation.

CHAPTER SIX

COAL PROPERTIES

6.1 INTRODUCTION

The range of chemical, physical and petrographic properties of coal are determined primarily by:

a) the rank attained by the coal (the term rank is used in the sense of thermal as proposed by Stach et al. 1982),
b) the depositional environment that the peat swamp formed in,
c) the degree of weathering, and
d) the degree of epigenetic mineralisation.

Properties such as volatile matter yield, calorific value, vitrinite reflectance, fluorescence of vitrinite and exinite macerals, and maceral composition are all influenced to varying degrees by both paleoenvironmental factors and rank, while weathering can have a major affect on all these properties, except maceral composition. Epigenetic mineralisation may also locally affect many of the coal properties (e.g. Section 5.3).

Studies on coal properties undertaken in New Zealand to date have relied heavily on drill core samples (e.g. Newman J. and Newman N. 1982, Black 1984, Newman J. 1985 and 1986). In these studies, trends evident in coal properties from isorank serial samples (i.e. samples from a common seam intersection) and between drill holes, have generally enabled lateral rank variations to be approximated, and consequently probable type influences on coal properties could be relatively accurately assessed. Such methods are however impossible in a study based on outcrop samples of low rank coal, where a relatively large lateral (generally 2-3km between creek exposures), and/or vertical (up to 800m) separation exists between samples. Consequently the relative influences of paleoenvironmental factors, rank, and weathering on coal properties are more difficult to evaluate.

In the following discussion Rotokohu coals are firstly classified according to their maceral-group composition, then specific coal types recognised are defined on the basis of their broad maceral, mineral matter (discussed previously in Section 5), and chemical characteristics. General conclusions on the probable paleoenvironmental setting of each coal type are made at this point, because aspects such as swamp drainage and oxygenation are relevant to the following discussions on other coal properties; microlithotype composition, vitrinite reflectance, volatile matter yield, and calorific value.

Microlithotype analysis of selected Rotokohu coals and a single sample from the Giles Formation are discussed, with comments made regarding the applicability of this technique to these coals, and vitrinite rich New Zealand coals in general. The probable influence of coal type on volatile matter yield, calorific value, and vitrinite reflectance is then evaluated, and the paleoenvironmental significance of the coal types outlined previously are then discussed in view of these influences.

Finally a broad discussion on rank assessment within Rotokohu coals is presented to complement aspects of coal geology discussed in the preceding sections. A discussion of sulphur is included in Section 5, because sulphur is an important constituent of the high temperature ash chemistry of some of the coals analysed.

6.2 MACERAL GROUP COMPOSITION

To determine maceral-group composition all samples analysed were expressed on a mineral-matter-free basis (mmf), and then plotted on a vitrinite-exinite-inertinite ternary diagram (Figure 6.1).

Like most New Zealand Tertiary coals (Black 1980) Rotokohu coals are inertinite poor. A number of the samples

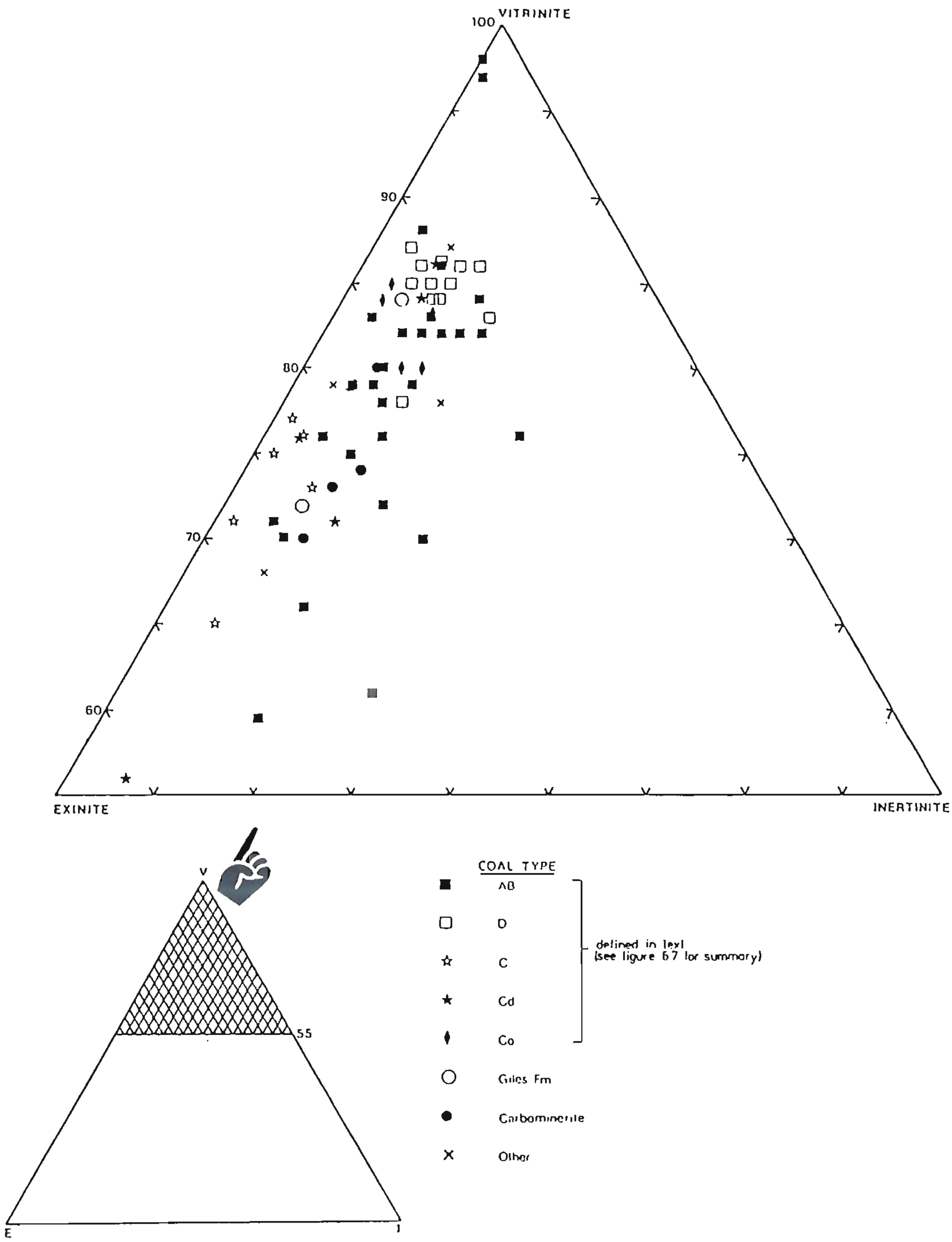


Figure 6.1: Maceral-group composition of Rotokohu coals (and two samples from the Giles Formation), expressed on a mineral-matter-free basis.

analysed were however exinite rich (up to 41%), resulting in a broad reactives rich composition field. A similar composition field was determined by Black (1984) for Miocene sub bituminous A* Mokau coals, but is generally atypical of most vitrinite dominated Cretaceous to early Tertiary New Zealand coals (Figure 6.2).

The large reactives rich composition field defined for Rotokohu coals invalidates generalisation of mean maceral-group composition, consequently the following discussion summarises the range of maceral composition observed. All values are expressed on a mineral matter free basis.

Total vitrinite within Rotokohu coals ranges from 55-98%, although most samples occur in the range 70-88%. The most abundant submacerals of the vitrinite group are well preserved telocollinite (formed by the infilling of cell cavities within telinite by the colloidal humic gel, collinite), and dense, fine grained desmocollinite (formed from strongly homogenised humic detritus). The proportions of these two vitrinite submacerals vary widely, resulting in a broad range of coal types (discussed in Section 6.3). Vitrodetrinite (small [<10mm] vitrinite detritus) is locally important (Figure 6.3), but generally occurs in small quantities. A trace of corpocollinite (isolated cell infillings occurring as discrete bodies with the reflectance of vitrinite) occurs in most samples.

Total exinite within Rotokohu coals ranges from 2-41%, with most samples occurring in the range 9-26%. Liptodetrinite (small exinite fragments of uncertain origin) is the dominant exinite maceral in most samples, occurring dispersed throughout the desmocollinite matrix. Cutinite is the next most abundant exinite maceral, commonly associated with telocollinite as leaf/stem sections, and locally is the

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* all rank terms refer to ASTM classification, unless otherwise stated

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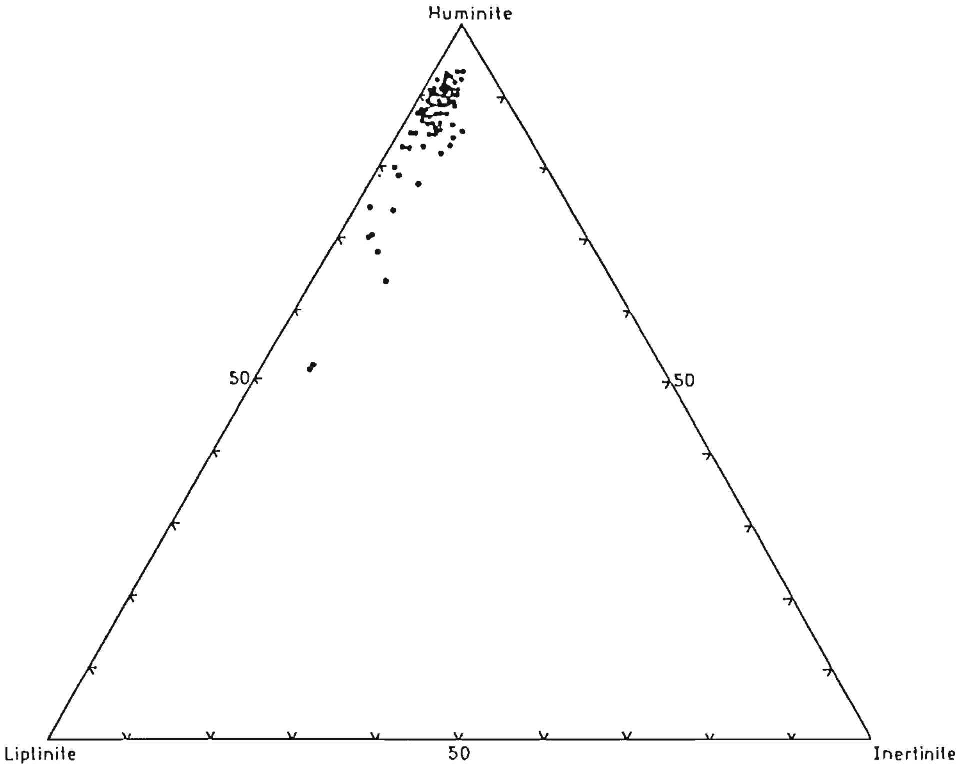
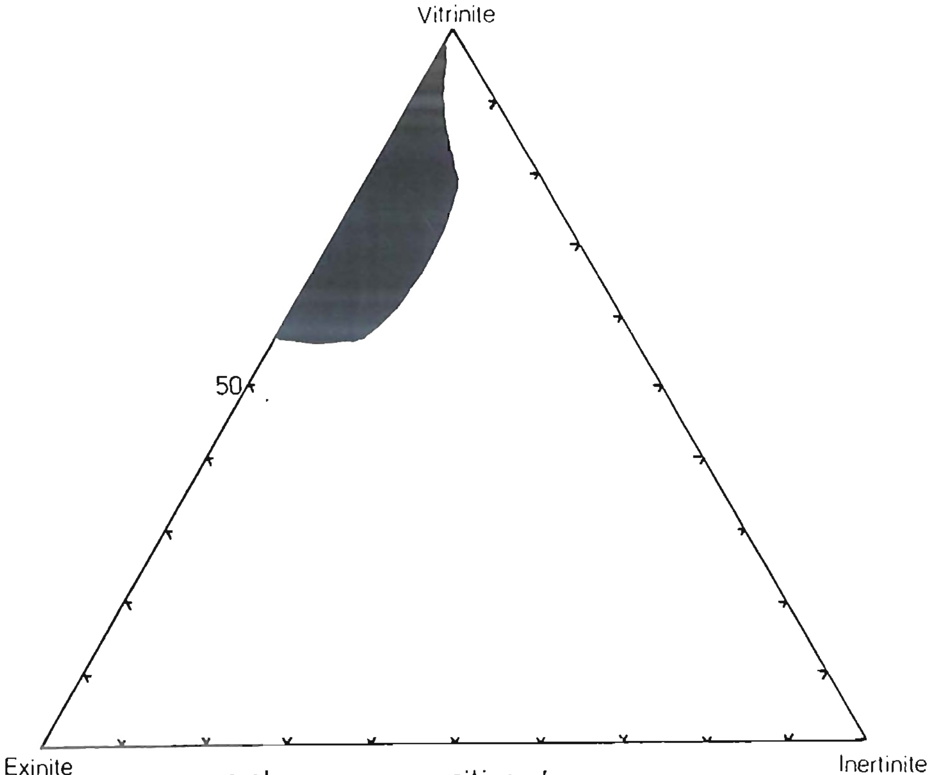


Petrographic composition of Mokau coals (core and outcrop samples).



maceral-group composition of
Rotokohu coals

<u>Figure 6.2</u>: Maceral-group composition of Rotokohu coals compared with Mokau coals. (Mokau field after Black, 1984).

dominant exinite maceral of leaf rich coals. Suberinite, sporinite and resinite (Figure 6.4) commonly occur in small quantities (1-3%), although sporinite is relatively abundant in some Type AB coals, and fine walled suberinite is abundant in Type D coal (Section 6.3)

Total inertinite ranges from 0-13%, with most samples in the range 2-8%. Fungal sclerotinite is the dominant inertinite maceral, occurring as isolated multi-or single-celled spores (Figure 6.5), and fine fungal hyphae attacking vitrinite macerals (Figure 6.6). Inertodetrinite (inertinite fragments which are too small to exhibit cell structure), and semifusinite (partially oxidised cell wall material) occur in smaller quantities, commonly in the order of 1-2%. Fusinite (oxidised cell wall material) and macrinite (oxidised peat, or gelified plant material) are both rare in Rotokohu coals, although pyrofusinite (charred plant material which has undergone incomplete combustion, and has a very high reflectance and distinctive yellow tinge in oil immersion), and degradofusinite (resulting from the decomposition of wood by fungal activity) have both been observed.

6.3 SPECIFIC ROTOKOHU COAL TYPES

6.3.1 Introduction

Coal "type" as used here broadly refers to the many coal properties which are known to be influenced by paleoenvironmentally induced variations in both the organic and inorganic fractions of the coal, and includes factors such as swamp drainage, pH, the general geochemical environment of the basin and the peat swamp, and the peat-forming floral assemblage. A discussion of coal type should not only include the coal macerals, but -where possible- chemical properties (e.g. volatile matter), vitrinite reflectance, and ash content and mineralogy, all of which are affected to varying degrees by the peat facies.

Many coal properties are also influenced by variations in coal rank, epigenetic mineralisation and weathering. Serial samples are commonly used to minimise variations in

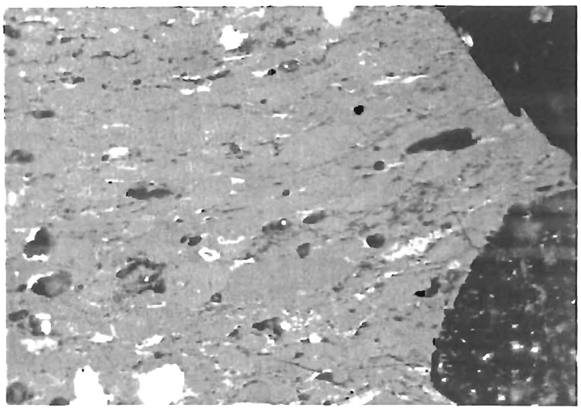


Figure 6.3: Locally vitrodetrinite rich coal (Sample 11872). Large resin bleb in right hand corner.

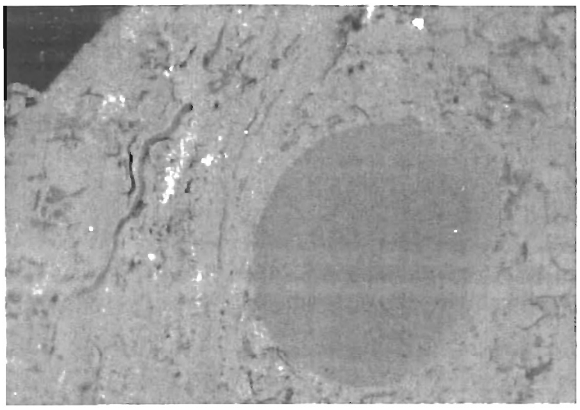


Figure 6.4: Large resin body within desmocollinite/lipodetr inite rich matrix (Sample 11873). Note slight oxidation rim around resin.

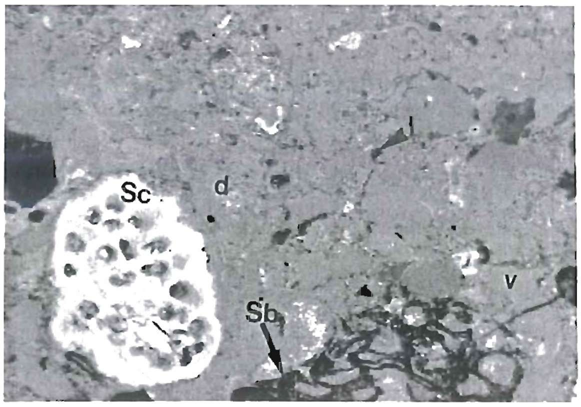


Figure 6.5: Sclerotinite(Sc), within vitrodetrinite(v)/ liptodetrinite(l)/ desmocollinite(d) association. Suberinite(sb) is also present (Sample 11872).

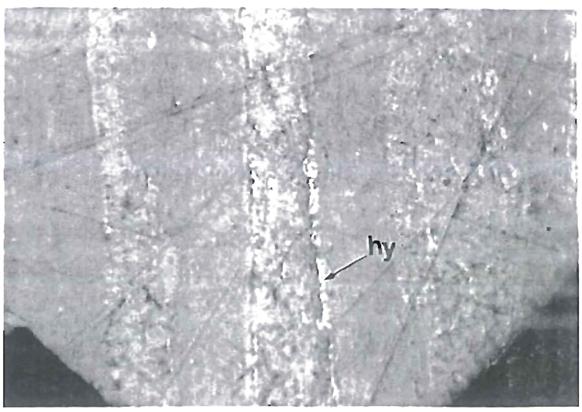


Figure 6.6: Fungal hyphae (hy) attacking telocollinite (Sample 11808).

coal properties due to rank variation (Newman J. 1985 and 1986). However, because this project is essentially a regional appraisal of the Rotokohu Coal Measures, the number of serial samples available is limited. In addition, all samples used in this thesis are outcrop samples, consequently care is needed when interpreting proximate and mineral matter analyses, as weathering can significantly affect many coal properties (Suggate 1959, Bowen 1964, Newman J. 1985 and 1986).

Five specific coal types are recognised within the Rotokohu Coal Measures, and the main distinguishing features of each type are identified in Figure 6.7. Most samples analysed are classified as one of these coal types on the basis of their broad maceral composition, inorganic mineralogy, and chemical analyses. Samples not allocated a type classification are inferred to probably represent "transitional" types, and/or weathered, or in some instances strongly mineralised samples.

6.3.2 Type AB

Type AB coal consists of two distinctive components, A and B.

i) Macroscopically the A component consists of large logs, clearly visible in outcrop forming massive bright vitrain lenses up to 0.25-0.30m thick (Figure 6.8), producing a distinctive (decimetre thick) banding. Microscopically the A component is dominated by distinctly "woody" telocollinite (Figure 6.9), commonly associated with suberinite of a characteristic "bark type" (Figure 6.10). Plies dominated by log accumulations (the A component) have extremely high Tissue Preservation Indices (TPI*).

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* TPI=the ratio of relatively well preserved tissues [telocollinite], to degraded vitrinite macerals desmocollinite and vitrodetrinite; as used by Newman J. 1986, modified from Diessel 1984).

Coal Type	Characteristics				
	HAND SPECIMEN	PETROGRAPHIC CHARACTERISTICS	MINERAL MATTER	PROXIMATE ANALYSES	INFERRED PALEOENVIRONMENT
Type AB: A component	massive, bright vitrain (logs/tree trunks) — combine to produce a strongly banded coal	Telocollinite rich. Very high TPI (>> 1) distinctive "bark-like" suberinite Inertinite sparse	the logs/tree trunks are commonly associated with clastic partings	both high VM/low reflectance relative to Type D coal (serial samples available)	brackish influenced, poorly drained hypautochthonous to in part allochthonous ? swamp with frequent flooding
Type AB: B component	finely banded clarain — combine to produce a strongly banded coal	Desmocollinite dominant. Low-mod TPI (< 0·5). Exinite commonly 10 - 15 % (liptodetrinite rich) no bleaching/corrosion of exinites Inertinite sparse to moderate (dominated by sclerotinite)	variable ash %	both high VM/low reflectance relative to Type D coal (serial samples available)	brackish influenced, poorly drained hypautochthonous to in part allochthonous ? swamp with frequent flooding
Type D	massive to faintly banded	Desmocollinite rich. Mod - low TPI (<0·5) Suberinite common (stem/root type) Vitrodetrinite relatively common Inertinite low. (< 6 %) Exinites commonly bleached/corroded	low ash < 4% db	high reflectance/ low VM relative to Type AB· coal	hypautochthonous to autochthonous, very well drained (possibly slightly raised ?) "wet" swamp
Type C	finely banded clarain (leaves and stems visible in hand specimen)	Telocollinite rich. High TPI (>0·7) very high exinite (cutinite dominant exinite maceral) Inertinite low	variable ash % concentrated in layers between leaves	low reflectance/very high VM (no serial samples available)	poorly drained, "stagnant" leaf accummulations
Type Cd	finely banded clarain	Telocollinite rich. High TPI (>0·6) Exinite rich (liptodetrinite dominant)	very high ash (8·1 - 24·1 % db)	mod. reflectance/ high VM (no serial samples)	poorly drained to possibly fluctuating water table, periods of high energy producing constant reworking and oxygen ?
Type Co	finely banded clarain	Desmocollinite rich. Low TPI (<0·5) Exinite poor (suberinite very low) Exinites commonly bleached/corroded	mod. ash (4·7 - 7·5 % db) dispersed in desmocollinite-rich matrix	high reflectance ?/ low VM (no serial samples)	relatively well drained, possibly brackish influenced, wet swamps

Figure 6.7: Summary of main coal type characteristics.

Figure 6.8: Massive vitrain lens, or log (A component), within Type AB coal at Giles Creek Mine.

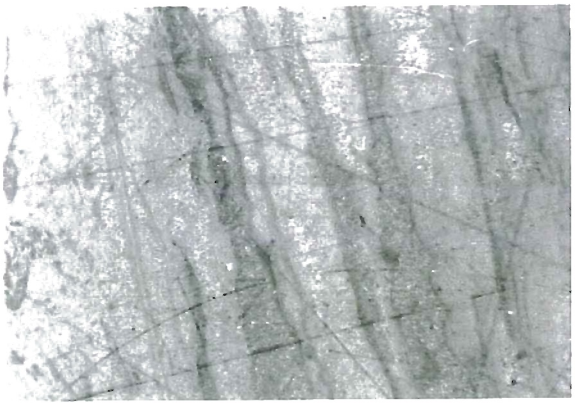


Figure 6.9: Microscopic view of A component (ie.logs) Type AB coals. Resin ducts interlayered with massive telocollinite (Sample 11812).

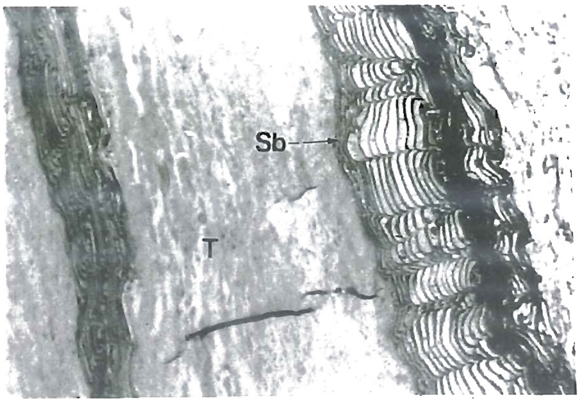


Figure 6.10: Massive telocollinite (T) interlayered with distinctive "bark like" suberinite (Sb) (Sample 11819).

ii) Macroscopically the B component consists of finely banded (millimetre to centimetre scale), moderately bright clarain (Figure 6.11). Microscopically it is dominated by the vitrinite maceral group, but contrasts with the A component by being relatively desmocollinite rich (Figure 6.12), resulting in a moderate to low TPI (<0.5).

Exinite is relatively common (10-15%), and locally very common (>20%) in the B component, and is dispersed throughout the fine desmocollinite groundmass. Liptodetrinite is the dominant exinite maceral, although sporinite is locally important. Exinite macerals are frequently relatively dark in colour, with little evidence of bleaching or corrosion, and large resin blebs are frequently observed both in hand specimen and under the microscope.

Inertinite content is moderate to high (generally 5-8% mmf) in comparison with other Rotokohu coal types, and is dominated by multi-cellular sclerotinite and fragmental inertodetrinite. Semifusinite occurs in small quantities (<2%), commonly as a halo of semifusinite around telocollinite macerals (Figure 6.13).

The desmocollinite-rich B component is the dominant component of Type AB coal. The interbedding of massive vitrain lenses (the A component), large resin blebs, and thin sedimentary partings within the clarain-rich B component produces a distinctly banded coal (Figure 5.7). The TPI for any given ply of Type AB coal is primarily a function of the relative abundance of logs or large vitrain lenses. Large vitrain lenses can dominate thin plies (<1m) and result in a vitrinite rich sample with a very high TPI(>2), while thick plies are dominated by the B component, and can be relatively exinite rich with a moderate to low TPI (generally 0.3-0.5, Figure 6.14). Consequently TPI is not a reliable criteria for characterising Type AB coals.

Serial samples from the thick basal seam at Giles Creek reveal that Type AB coals have relatively high volatile matter (>48.5% dmml/2sf basis, as proposed by Newman N.A. 1985) and low reflectance compared with Type D coal (dis-

Figure 6.11: Moderately bright clarain (B component, macroscopic appearance), and large resin bleb. Type AB coal Giles Creek Mine.

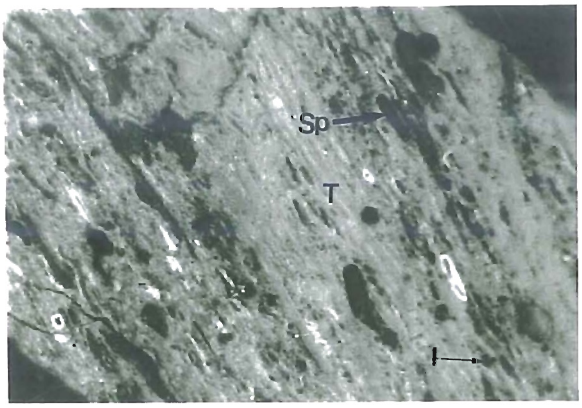


Figure 6.12: Liptodetrinite rich B component (microscopic appearance). Relatively common sporinite(sp) and liptodetrinite(l), in a desmocollinite rich matrix, with thin telocollinite layers (T) (Sample 11814).

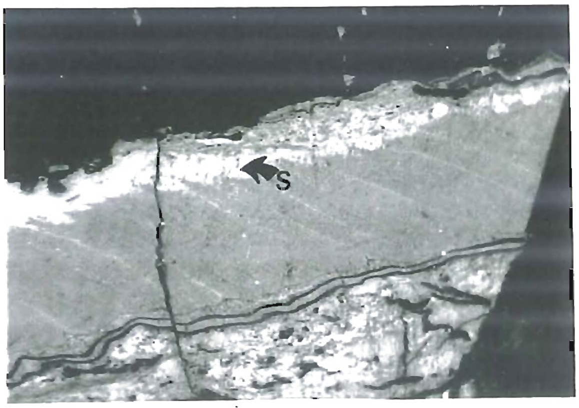


Figure 6.13: Telocollinite grading into semifusinite (the relatively high reflecting halo) (Sample 11867).

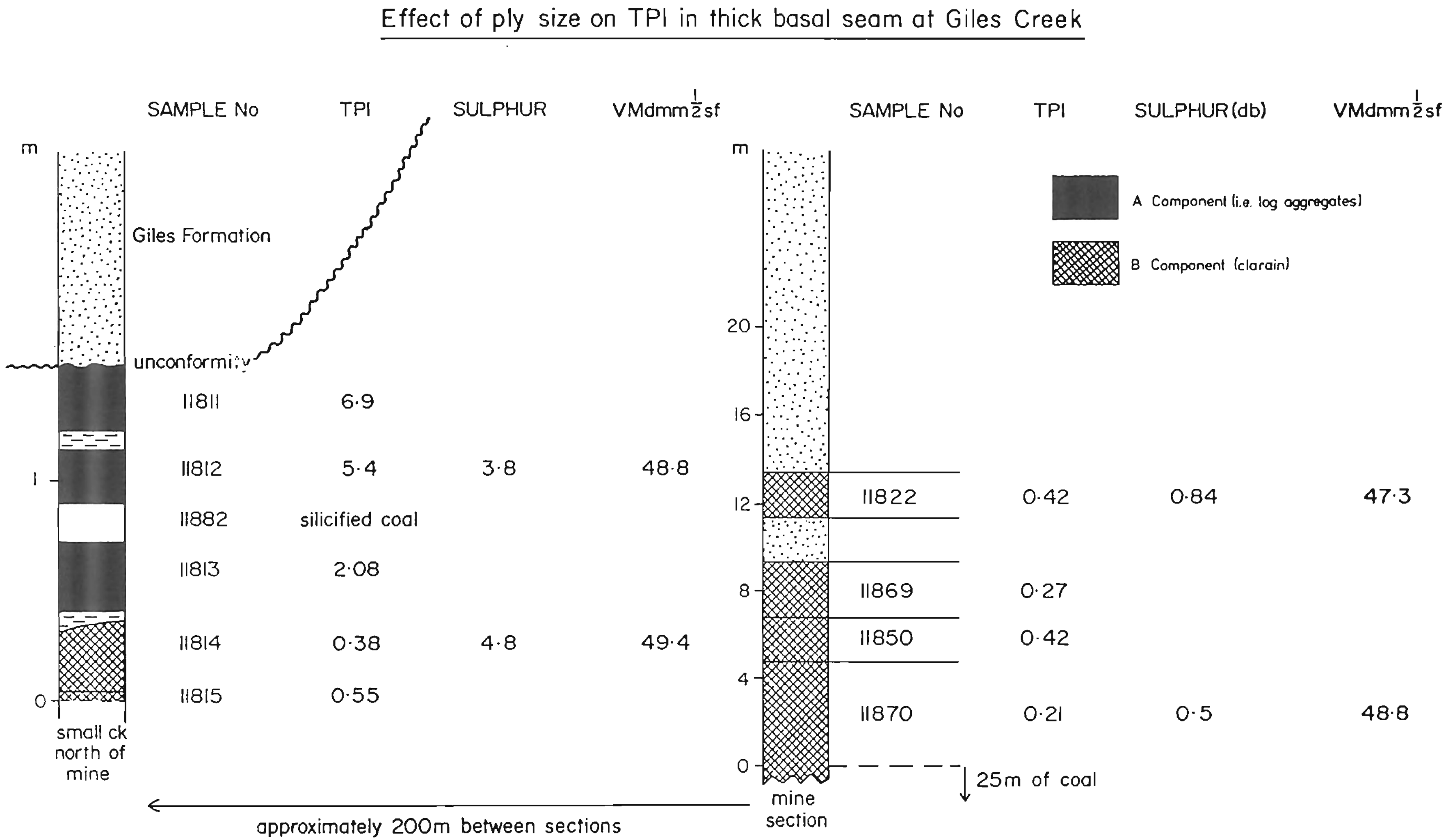


Figure 6.14: Affect of log accumulations (solid shading) on T.P.I. within Type AB coal. Logs can dominate thin lies, producing a very high T.P.I. Also note the affect of the Wanganui unconformity on the sulphur content.

cussed in Section 6.6), and variable ash values (4.3-29.1% db, Appendix 8).

X-ray diffraction of low temperature ash residues indicates a mineral assemblage dominated by quartz and relatively well ordered kaolinite, with a faint muscovite trace present in medium to high ash samples (Section 5.2). High temperature ash chemistry usually indicates a strong detrital mineral matter component, although low ash samples commonly contain relatively large amounts of organically bound mineral matter. Silicified horizons are common in Type AB coal, and can strongly influence the mineral matter composition of the surrounding coal (Section 5.3).

6.3.3 Type D

Macroscopically Type D coal is massive to faintly banded (millimetre scale), moderately bright clarain, commonly with a moderately well developed concoidal fracture, and generally lacks clastic sedimentary partings.

Type D coal has distinctive petrographic characteristics. It is vitrinite rich, being dominated by a dense desmocollinite groundmass, with telocollinite generally subordinate, while vitrodetrinite is common relative to other Rotokohu coal types. This desmocollinite/vitrodetrinite rich maceral association results in a moderate to low TPI (0.3 -0.5), and is one of the characteristics of Type D coal.

The inertinite content of Type D coal is low to moderate (<6%), and is usually dominated by inertodetrinite, with sclerotinite sparse in comparison to Type AB coal. Semifusinite is locally important, usually gradational to telocollinite in plant tissues.

Exinite is common (approximately 10%), but is generally less abundant than in the desmocollinite dominated B component of Type AB coal. Suberinite, of a distinctive "root/stem" type (Figure 6.15), is the dominant exinite maceral (4-6%), and is characteristic of Type D coal. Cutinite and liptodetrinite are the next most abundant exinite macerals, with resinite and sporinite occurring in smaller quantities. The cutinite is commonly bleached and/or corroded.

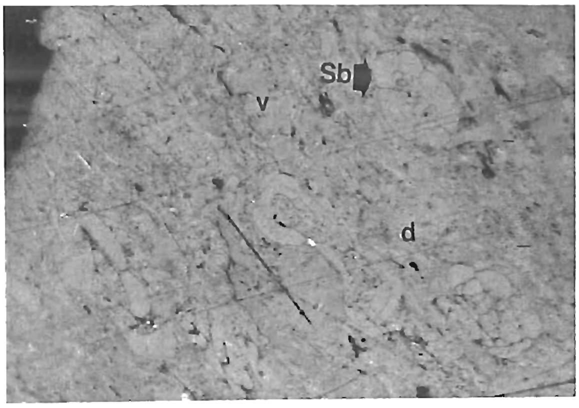


Figure 6.15: Distinctive root/stem cross-section suberinite (sb), within desmocollinite (d)/ vitrodetrinite (v) rich Type D coal (Sample 11809).

Serial samples from Giles Creek indicate that Type D coal has a relatively low volatile matter yield (always <48%, dmm1/2sf) and high reflectance compared with Type AB coal, and low to very low ash contents (always <4.5% db, and commonly <3% db). X-ray diffraction of low temperature ash residues indicates a mineralogy dominated by quartz, commonly in association with gypsum (Appendix 9). Kaolinite is present in some samples, while smectite is common in high ash plies near the top of the second seam at Giles Creek Mine. The high temperature ash chemistry of Type D coal is usually strongly influenced by organically bound elements (Ca, Mg, Na, S), previously interpreted in Section 5 to indicate a relatively small clastic mineral matter content.

6.3.4 Type C

Macroscopically Type C coal consists of thin seams (<1.5metres) of moderately bright clarain. Individual leaves and stems are clearly visible in hand specimen, set in a relatively dull fine grained matrix. Wisps of chocolate brown carbonaceous mudstone and/or thin (<5cm) lenticular mudstone partings are present in most seams.

Microscopically Type C coal is relatively exinite rich (21-32%) and inertinite poor (<4%) in comparison to most other Rotokohu coal types. The exinite is dominated by well preserved cutinite (10-15%), and liptodetrinite (4-16%), while suberinite, resinite and sporinite occur in small quantities (<2%).

Inertinite consists predominantly of sclerotinite (up to 2%), with a trace of semifusinite and inertodetrinite commonly occurring in association with desmocollinite/clay rich horizons between telocollinite/cutinite layers. Fusinite does not occur in Type C coal.

Telocollinite is the dominant vitrinite maceral, and is invariably interlayered with well preserved cutinite forming a distinctive "leaf coal" (Figure 6.16). This telocollinite/cutinite association results in a high TPI (>0.7), and is the characteristic feature of Type C coal.

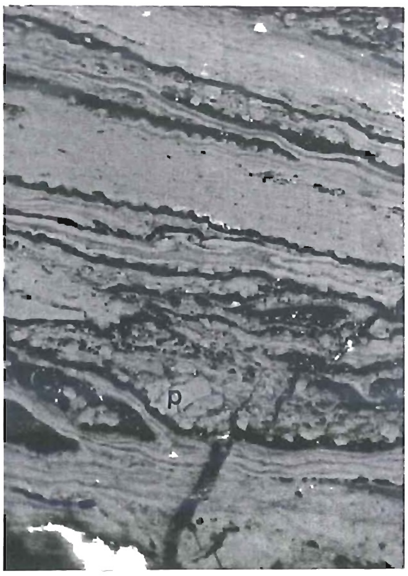


Figure 6.16: Type C coal. Well preserved layers of toothed cutinite, massive telocollinite, and phyllovitrinite (P, "leaf" vitrinite) [Sample 11832].

Proximate analyses are available for four Type C coals, and reveal a variable ash content (3.9-13.4% db). Petrographic work indicates that the ash consists of quartz and clay minerals concentrated in desmocollinite/liptodetrinite rich layers between leaves/stems. The high temperature ash chemistry is dominated by SiO_2 and Al_2O_3, and is inferred to imply a strong detrital component (Section 5.5).

Although serial samples are not available to allow direct comparison of Type C with other coal types of equal rank, it is evident that these coals always have high volatile matter yields (always >51.5% dmml/2sf) relative to other coal types within the coalfield (Section 6.6). A relatively high volatile matter yield is characteristic of similar European and American "leaf" coals (Stach et al. 1982).

6.3.5 Type Co

Type Co coal is vitrinite rich (80-86%), inertinite poor (2-6%). Exinite is relatively common (10-15%), but distinctly less abundant than in Type C coals. Desmocollinite is the dominant vitrinite maceral, and well preserved telocollinite is relatively sparse. This high desmocollinite/low telocollinite association results in a characteristic low to very low TPI for Type Co coals (always <0.4%).

Liptodetrinite is the dominant exinite maceral (5-9%), occurring as isolated fragments within the dense desmocollinite matrix. Cutinite and resinite are the next most abundant exinites (2-4%), with minor suberinite (1-2%) and usually a trace of sporinite.

Sclerotinite is generally the dominant inertinite maceral, with both large isolated teleutospores and fine fungal hyphae common, while semifusinite and inertodetrinite occur in small quantities (generally a trace to 1-2%).

Proximate analyses are available for four samples of Type Co coal. These analyses indicate a moderate ash content (4.7-7.5% db), and distinctly low volatile matter yields (46.7-48.9% dmml/2sf) compared with Type C and, most Type AB coals. Petrographic study indicates that the mineral matter is finely dispersed within the desmocollinite matrix. The high temperature ash chemistry is dominated by organically bound elements (Ca, Mg and S), and low temperature ash residues are dominated by quartz and gypsum. Both these features are inferred to suggest a small clastic mineral matter content relative to other coal types (Section 5).

In terms of broad mineral and maceral characteristics, Type Co coal is similar to Type D coal, however Type Co coal contains distinctly less suberinite and vitrodetrinite than Type D coal, and generally has slightly higher ash values.

Type D coal also has an extremely localised distribution, being restricted to the Giles Creek Mine, and is inferred to reflect an unusual depositional environment (i.e. a peat swamp which developed above an abandoned channel sequence; Chapter 3). The subtle differences between Type D and Co coal are therefore significant to the paleoenvironmental interpretation of the coal measures, and justify the distinction between the two coal types.

6.3.6 Type Cd

Type Cd coal is exinite rich (generally >19%) inertinite poor (always <6%). Liptodetrinite and inertodetrinite are the dominant exinite and inertinite macerals, both occurring in desmocollinite/mineral matter rich associations between telocollinite layers. The vitrinite component is telocollinite rich, desmocollinite poor, resulting in a relatively high TPI (>0.6), and is one of the characteristics of Type Cd coal (Figure 6.7). Proximate analyses indicate that Type Cd coal contains a relatively high ash content (8.1-24.1% db), with variable volatile matter yields (46.9-53.2% dmml/2sf). The variability of the volatile matter yield may partly result from the high ash content which makes correction for mineral matter less reliable, but is also directly attributable in some samples to variations in exinite content (Section 6.6.2).

X-ray diffraction of low temperature ash residues indicates a mineral matter assemblage of quartz, and relatively well ordered kaolinite and muscovite (Appendix 9). In polished sections the mineral matter occurs in detrital layers associated with liptodetrinite, inertodetrinite and desmocollinite. The high temperature ash chemistry reflects the strong clastic mineral matter component, being relatively rich in SiO_2, Al_2O_3 and K_2O, and poor in organically bound elements Ca and Mg.

6.3.7 Conclusions

The following broad discussion is included to summarise aspects of the depositional environment of each coal type (essentially the swamp water level), as a limited knowledge of the paleoenvironmental setting is pertinent to understanding other coal properties such as microlithotypes, vitrinite reflectance, volatile matter yield and calorific value. The paleoenvironmental significance of the coal types recognised are discussed in detail with regard to all known influences on coal properties in Section 6.6.

Frequent clastic partings and variable ash contents within Type AB coal suggest a periodically very high swamp water table. Log accumulations preserved as aggregates of large vitrain lenses are commonly associated with high ash layers and resin blebs, suggesting a transported, or possible flood assemblage, and result in a variable TPI for Type AB coals. Type AB coals are therefore considered to represent relatively poorly drained swamps, although the controls on various coal properties in Type AB coal are complex, and are discused in more detail in Section 6.6.

The very low ash content of Type D coal, and moderate to low ash content of Type Co coal, suggests that these two coal types represent relatively well drained swamps compared to most Rotokohu coal types. A low water level generally allows greater oxygenation during peatification, and consequently favours increased degradation of organic material within the peatigenic layer, where aerobic bacteria are active (Flaig 1968, Stach et al. 1982, Newman J. 1985). A high level of peat degradation is consistent with the moderate to low TPI for these two coal types, and supports the conclusion of relatively good swamp drainage inferred from the low ash contents.

The very high TPI of Type C coal results from the characteristic layering of telocollinite and well preserved cutinite macerals, suggesting a poorly drained yet "low energy" swamp, with very little mechanical and/or biochemical degradation of the organic material. The variable ash content (3.9-13.4% db), concentration of mineral matter in discrete layers, and the strong clastic mineral matter component indicated by most ash analyses also suggest a high water table.

The high clastic mineral matter content and high TPI of Type Cd coal are consistent with deposition in a poorly drained swamp, with frequent incursions of clastic material. The characteristically high liptodetrinite content suggests a greater degree of mechanical and/or biological degradation relative to Type C swamps, with the clastic mineral matter and degraded macerals (desmocollinite, vitrodetrinite, liptodetrinite, and limited inertodetrinite) occurring as a characteristic "detrital" association between telocollinite layers.

6.4 MICROLITHOTYPE ANALYSIS

6.4.1 Introduction

Microlithotypes are naturally occurring maceral associations with a minimum band width of 50 microns (International Handbook of Coal Petrology 1971). One of the principal uses of microlithotypes is in the field of peat-facies analysis, where specific groups of microlithotypes are considered characteristic of distinctive swamp environments.

Hacquebard and Donaldson (1969) considered that peat swamp paleoenvironments are principally related to water depth, with the water depth affecting both the type of vegetation that developed, and the formation and preservation of petrographic constituents. On the basis of this assumption, four swamp facies originally defined by Teichmuller (1950; in Hacquebard and Donaldson 1969) are incorporated with three water level zones of Osvald (1937; in Hacquebard and Donaldson 1969), to produce a four-component peat-facies diagram (Figure 6.17).

Each zone within the peat-facies diagram is defined by particular groups of microlithotypes, and is inferred to represent a specific moor environment. The microlithotype groupings which define the apices of the triangular peat-facies diagram are known as components, with four components recognised; A, B, C and D.

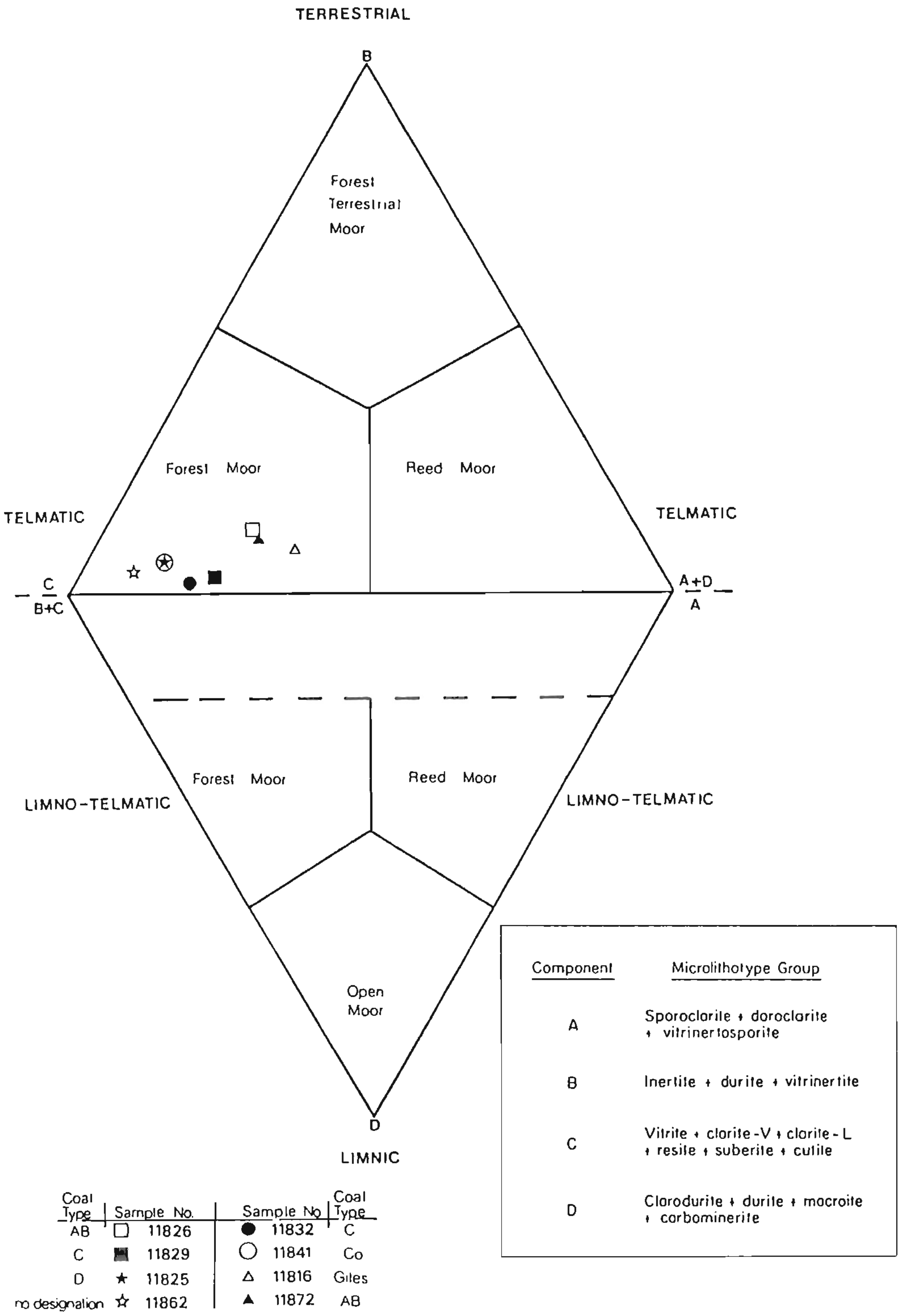


Figure 6.17: Peat facies analysis of samples from the Rotokohu Coal Measures, and a single sample from the Giles Formation (11816), based on microlithotype group composition (Appendix 6). Peat facies diagram slightly modified after Hacquebard and Donaldson (1969), Marchioni (1980) and Diessel (1984). Microlithotype groupings used (inset) and coal type designation are also shown.

A-components are essentially based on the maceral sporinite, and are inferred to primarily represent reed moor peat-facies. B-components are based on inertinite macerals, and are inferred to represent forest moor peats formed under partially oxidising conditions. C-components are comprised of reactives rich macerals vitrinite and exinite (excluding sporinite), and are inferred to represent forest moor peats formed under "wet" swamp conditions, while D-component microlithotypes are based on the presence of mineral matter, and are inferred to represent poorly drained swamps.

The individual microlithotypes recognised in this study are those defined by the I.C.C.P.(1971), with refinements proposed by Marchioni (1980), and are shown in Figure 6.18. The microlithotype groupings used in this thesis are shown in Figure 6.17, and are essentially those proposed by Marchioni (1980), but with the single following refinement;

a) Vitrinertite-V, although dominantly vitrinite, is classified as a "B" component because rapid subsidence generally favours the development of vitrinite rich coals (Smith 1968, Marchioni 1980). Small quantities of inertinite are therefore probably more environmentally significant in vitrinite rich coals associated with active tectonic basins, than is likely to be the case in coals associated with cratonic regions.

In plotting a microlithotype on the peat-facies diagram, if the D-components constitute >20% of the total then the B and C-components are combined and the lower or "dull" triangle is used. If D-components constitute <20% of the total then D- and A-components are combined and the upper, or "bright" triangle is used.

In view of the time-consuming nature of microlithotype analysis, a small suite of eight samples was selected on the basis of their broad maceral characteristics.

Coal-mineral associations.

Coal intergrown with a certain mineral or a mineral group	Composition	Collective name for any association of coal and minerals
Carbargilite	coal + 20 — 60 % by vol. of clay minerals	
Carbopyrite	coal + 5 — 20 % by vol. of sulphide minerals	
Carbankerite	coal + 20 — 60 % by vol. of carbonate minerals	Carbominerite
Carbosilicite	coal + 20 — 60 % by vol. of quartz	
Carbopolyminerite	coal + 20 — 60 % by vol.* of various minerals	

* The lower limit can be reduced to 5 %, depending on the content of pyrite.

Maceral composition (mineral-free)		Microlithotype	Maceral-group composition (mineral-free)	Microlithotype group
Monomaceral				
Co	> 95 %	(Collite)*	V > 95 %	Vitrite
T	> 95 %	(Telite)*		
VD	> 95 %			
S	> 95 %	Sporite		
Cu	> 95 %	(Cutite)*		
R	> 95 %	(Resite)*	E (L) > 95 %	Liptite
A	> 95 %	Algite		
LD	> 95 %			
Sf	> 95 %	Semifusite		
F	> 95 %	Fusite	I > 95 %	Inertite
Sc	> 95 %	(Sclerotite)*		
ID	> 95 %	Inertodetrite		
M	> 95 %	(Macroite)*		
Bimaceral				
V + S	> 95 %	Sporoclarite		
V + Cu	> 95 %	Cuticoclarite	V + E (L) > 95 %	Clarite
V + R	> 95 %	(Resinoclarite)*		V, E(L)
V + LD	> 95 %			
V + M	> 95 %			
V + Sf	> 95 %			
V + F	> 95 %		V + I > 95 %	Vitrinertite
V + Sc	> 95 %			V, I
V + ID	> 95 %			
I + S	> 95 %	Sporodurite		
I + Cu	> 95 %	(Cuticodurite)*		
I + R	> 95 %	(Resinodurite)*	I + E (L) > 95 %	Durite
I + LD	> 95 %			I, E(L)
Trimaceral				
V, I, E	> 5 %	Duroclarite	V > I, E (L)	Trimacerite
		Vitrinertoliptite	E > I, V	V, I, E(L)
		Clarodurite	I > V, E (L)	

* The terms in parentheses are not at present in use.

Co = Collinite; T = Telinite; VD = Vitrodetrinite; S = Sporinite; Cu = Cutinite; R = Resinite; A = Alginite; LD = Liptodetrinite; M = Macrinite; Sf = Semifusinite; F = Fusinite; Sc = Sclerotinite; ID = Inertodetrinite; V = Vitrinite; F = Fusinite; L = Liptinite; I = Inertinite.

Figure 6.18: Summary diagram of the microlithotypes (from Stach et al. 1982)

6.4.2 Discussion

The eight samples analysed are all dominated by C-component microlithotypes vitrite and clarite-V, and plot in the "Telmatic Forest Moor" sub-area of the peat-facies diagram (Figure 6.17). This zone is commonly inferred to suggest a dominance of "woody" vegetation within wet peat swamps (Hacquebard and Donaldson 1969, Marchioni 1980, Diessel 1984), and is consistent with the limited palynological data which also suggests a dominance of beach and podocarp vegetation in samples collected near coal seams (Mildenhall 1976).

The relative abundance of individual microlithotypes varies between samples, and reflects differences in coal types within the broad "Telmatic Forest Moor" classification.

Samples 11826 and 11872, which are classified as Type AB coal on the basis of their maceral, ash and chemical characteristics, are dominated by vitrite and liptoclarite-V. Cuticoclarite-V is rare, while vitrinertite-V and duroclarite are present in small quantities. Almost all D-components comprise carbopyrite, reflecting the marine influence within the Thomson Member (Chapters 3 and 5). Carbargillite and carbosilicite are rare, suggesting that the mineral matter is dispersed within the clarite/vitrite rich matrix. According to the peat-facies diagram Type AB coals have a slightly more herbaceous component than other coals within the Rotokohu Coal Measures.

Samples 11829 and 11832, which are classified as Type C coals, are dominated by clarite-V, with cuticoclarite-V more abundant than liptoclarite-V, suggesting a dominance of well preserved leaves/stems. Vitrinertite-V is very low, while carbargillite is more abundant than in the other Rotokohu coals analysed. These features are suggestive of a "leaf coal" deposited in a very wet swamp, with the mineral matter generally concentrated in distinct layers between leaves. The high carbopyrite content of sample 11829 reflects its stratigraphic position within the marine influenced Thomson Member.

Samples 11841 and 11825, are classified as coal types Co and D respectively. Both are strongly dominated by liptoclarite-V and vitrite. Vitrinertite-V is more abundant than in the other samples analysed, while carbominerite is rare. This microlithotype association is interpreted as representing a relatively well drained swamp with a greater degree of tissue degradation relative to Type C swamps, producing relatively low carbominerite/cuticoclarite-V contents, and high liptoclarite-V/Vitrinertite-V contents.

According to the peat-facies diagram, both coal types Co and D are inferred to be derived predominantly from "woody" vegetation, but microlithotype analysis is unable to distinguish between these two coal types.

Sample 11862, has unusual maceral, mineral matter and chemical characteristics, and consequently is not allocated a coal type grouping. This sample is extremely rich in vitrite, with abundant liptoclarite-V, and almost no carbominerite. According to peat-facies analysis these characteristics suggest a relatively well drained, and/or protected, wet swamp (hence the very low mineral matter in the microlithotype, maceral and proximate analyses), derived from a distinctly "woody" flora.

Sample 11816 from the Giles Formation at Giles Creek is not assigned a coal type grouping. Liptoclarite is the dominant microlithotype, and both A- and D-components are relatively abundant compared with the Rotokohu coals analysed. These features may imply a slightly more herbaceous peat forming flora than in coal seams from the Rotokohu Coal Measures.

A more herbaceous flora may support the marginal marine depositional environment previously inferred in Chapter 2 for the mixed-lithotype of the Giles Formation, as herbaceous plants are generally considered more characteristic of poorly drained lake margins or marginal marine environments (Teichmuller M and Teichmuller R 1968b, Hacquebard and Donaldson 1969).

6.4.3 Conclusions

Microlithotype analyses are of limited use for paleoenvironmental analysis within reactives rich Rotokohu coals, and low ash vitrinite rich New Zealand coals in general, where C-components predominate (e.g. Sykes 1985). The peat-facies classification of each sample can be estimated relatively accurately from maceral analyses, and in view of the greater speed and much reduced opportunity for operator error, standard maceral analysis is probably the more appropriate technique for paleoenvironmental analyses of New Zealand coals.

The inherent assumptions within the scheme that specific microlithotypes are indicative of specific depositional environments must be treated with caution. The assumption that sporinite abundance is indicative of wet environments is lately being questioned (Diessel pers. comm.), and the paleoenvironmental significance of the microlithotype vitrinertite can also be problematic because:

a) the microlithotype technique does not distinguish allochthonous from autochthonous inertinite,

b) the presence of sclerotinite is commonly considered more characteristic of reed moor than forest moor environments (Teichmuller M. and Teichmuller R. 1968), and the abundance of this maceral is not necessarily attributable to oxidising conditions, yet sclerotinite is commonly classified as a B-component.

c) stems are characterised by well preserved telocollinite and cutinite macerals, yet this maceral association is classified as a C-component, and is considered indicative of "woody" vegetation.

Application of microlithotype analysis to a range of New Zealand coals of known coal type, in conjunction with palynological studies, is recommended for evaluating the usefulness of this technique to paleoenvironmental analysis of New Zealand coals.

The principal advantage of microlithotype analysis for New Zealand coals is likely to be that the technique attempts to quantitatively measure maceral associations. On this basis the technique, in a modified form, may have applications in the field of coal utilisation studies such as those being undertaken by Briquet (in prep.).

6.5 VITRINITE REFLECTANCE

6.5.1 In-Sample Reflectance Variations Between Vitrinite Macerals

In many low rank sub bituminous coals differences in reflectance between various vitrinite submacerals can be significant. Overseas researchers generally suggest this in-sample reflectance variation diminishes rapidly with increasing rank, and is negligible in higher rank bituminous coals (Cameron et al. 1984). However, recent research by Newman J. (1985 and 1986) on vitrinite rich West Coast coals suggests that isorank variation in vitrinite reflectance increases as rank increases, and is particularly significant in high volatile bituminous rank coals.

In an effort to limit undesirable in-sample variation, reflectance measurements are usually restricted to one vitrinite submaceral, either large, structureless telocollinite in black coals, or eu-ulminite B in brown coals (McCartney and Teichmuller M. 1972, Cameron et al. 1984). Large, generally structureless telocollinite was selected as the most suitable maceral for reflectance studies in Rotokohu coals. The reflectance of desmocollinite was also measured for some samples, to determine if any significant variation exits between the two dominant vitrinite macerals in Rotokohu coals, and is distinguished graphically on reflectograms presented in Appendix 7.

For all Rotokohu coals analysed, the reflectance distribution of desmocollinite generally conforms to, or is slightly lower than telocollinite within the same sample. The similarity of the two reflectance distributions implies a relatively uniform chemical composition, hence probably a similar source. A particularly weak desmocollinite reflectance (for any given rank) implies a significantly more hydrogen rich chemistry, possibly suggesting derivation from a more cellulose-rich (herbaceous) flora (Stach et al. 1982, p 27).

Marked variations in reflectance between vitrinite macerals are exhibited by sample 11861 from Hart Creek (Figure 6.19). In this sample two distinctive types of "telocollinite" were measured:

a) massive, relatively bright, fine telocollinite, and
b) massive to faintly structured, "resinous"/dull telocollinite.

The difference in mean reflectance between these two vitrinite macerals is $\bar{R}o$=0.10%, and is similar to differences observed by Cameron et al. (1984) between "eu-ulminite A and B" within Greek lignites and sub bituminous coals (Figure 6.19).

The desmocollinite reflectogram of sample 11861 shows a close approximation to that of the "bright" telocollinite, suggesting that this is the "true" reflectance of this sample (in view of the similarity noted between telocollinite and desmocollinite reflectances in the other samples analysed). Further evaluation of the degree and significance of in-sample reflectance variation exhibited by vitrinite/huminite macerals within low rank New Zealand coals is recommended in view of the notable variation outlined above.

6.5.2 Vertical and Lateral Trends

i) Introduction

Coal Creek (L29 206204 to L30 239179), was selected as the site of a reconnaissance study of vertical reflectance variations in the Rotokohu Coal Measures. Eleven samples were examined from this section, with a further 4 samples obtained from Brown Creek approximately 1.5-2km to the north (samples indicated by "B" on Figure 6.20). The lower samples are from thin (<1metre) coal seams within the Thomson and lower Camp Members, while samples from the upper Camp Member and Larry Schist Conglomerate are predominantly thin carbominerites and log accumulations.

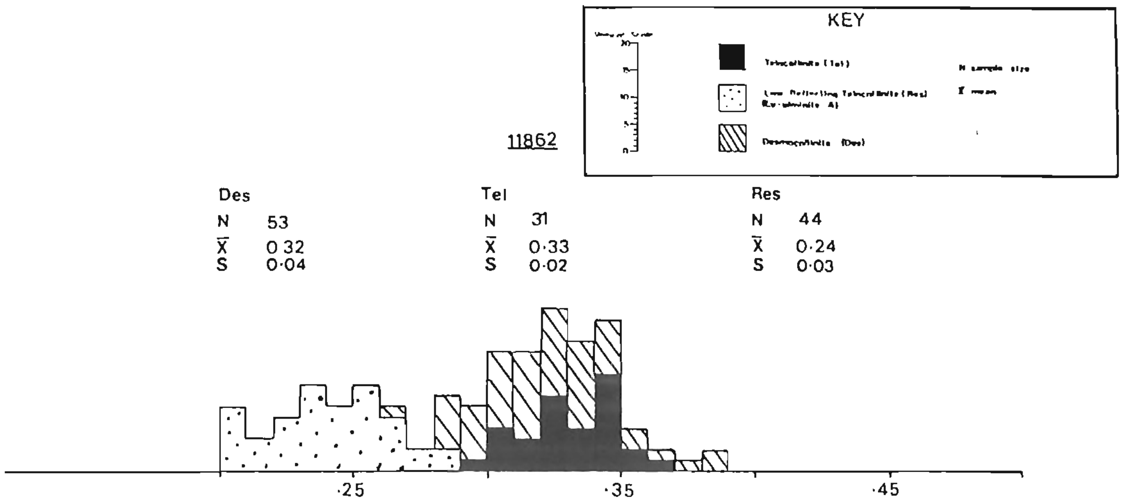


Fig. 6·19A

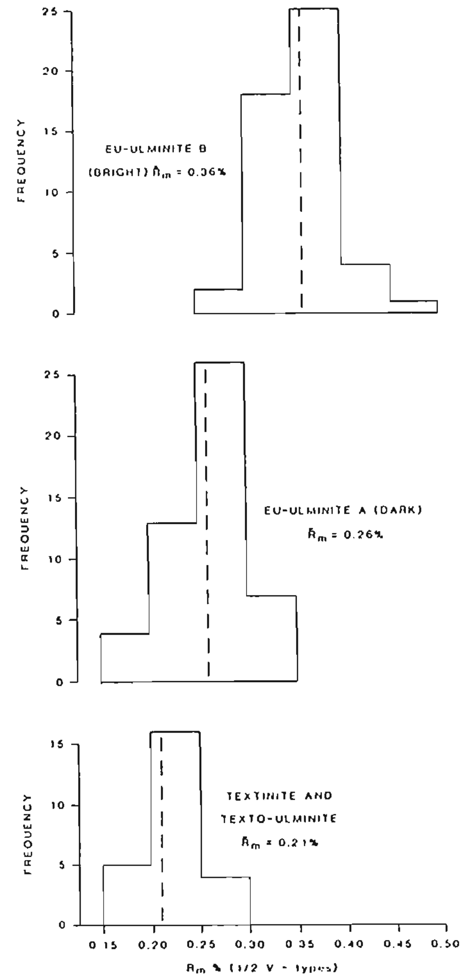


Fig. 6·19B Reflectance histograms for huminite macerals in sample 4 (Dilofo, Orestias. Dashed lines indicate position of arithmetic mean. ½ V-type: reflectance range from 0.15–0.19%, 0.20–0.249% etc.

Figure 6.19: A) Reflectogram for sample 11862 showing in-sample variation between vitrinite macerals.
B) Reflectograms for huminite macerals in Greek sub bituminous coal (from Cameron et al. 1984).

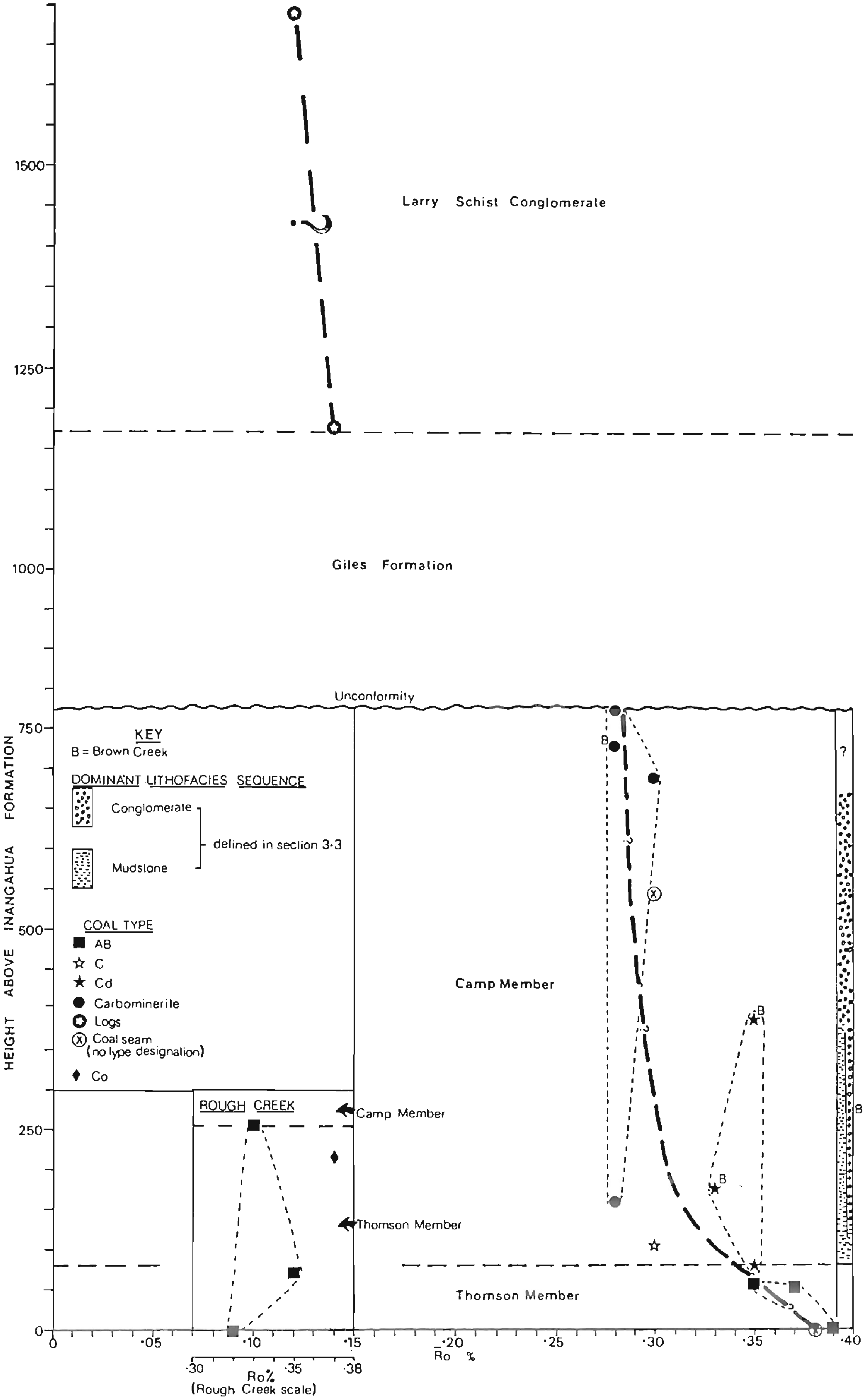


Figure 6.20: Depth/reflectance relationships at Coal Creek.

A further series of 21 samples, predominantly from the base of the coal measures, were analysed in an attempt to determine any lateral reflectance trends. Most samples from the base of the coal measures, except samples 11829 (Type C coal; from the Gorgy Creek area) and 11862 (no type designation; from Hart Creek), are classified as Type AB coal (Section 6.3). Three samples from the Giles Formation at Giles Creek were also included for analysis, but are not given type classifications.

ii) Discussion

Overseas research suggests that vitrinite reflectance generally shows a good positive correlation with increasing depth of burial at relatively high ranks (medium volatile bituminous and greater ranks; Teichmuller M. and Teichmuller R. 1968a, Stach et al. 1982). At lower ranks (less than medium volatile bituminous) the relationships between vitrinite reflectance and depth of burial are less well understood, and consequently vitrinite reflectance is not universally accepted as a suitable rank indicator (e.g. McCartney and Teichmuller 1972).

Reflectance values at Coal Creek vary from a maximum of $\bar{R}o$=0.39% at the base, to a minimum $\bar{R}o$=0.12% at the top of the section (Figure 6.20). The degree of lateral rank variation between samples from Coal and Brown Creeks cannot be adequately resolved because of a lack of suitable proximate analyses (with bed moisture values). Similar lateral separations (1.5-2km) between samples in the Greymouth Coalfield are sufficient to affect rank (Newman J. 1985), and this lateral separation must be considered as a possible influence on the reflectance distribution. However, the relatively uniform reflectance between samples of equal type from both creek sections suggests that any lateral reflectance variation due to rank changes is minimal.

Two alternative hypotheses are presented to explain the reflectance distribution observed at Coal Creek.

Hypothesis 1: A "best-fit line" has been sketched through the sample points on Figure 6.20 according to the hypothesis that vitrinite reflectance will broadly increase as the depth of burial increases. Although there appears to be a marked initial reduction in reflectance with depth in the Thomson and basal Camp Members, overall there seems to be little relationship between reflectance and depth.

The major difference in reflectance between carbominerites from the Rotokohu Coal Measures, and log accumulations from the Larry Schist Conglomerate may result from type variations, although it appears to be more directly related to the regional Wanganui unconformity. This relationship may however be apparent, as samples are not available from the intervening Giles Formation at Coal Creek.

Depth of burial is not the only factor involved in organic metamorphism. Temperature and time are also important controls (Teichmuller M. and Teichmuller R. 1968a, Hood et al. 1975, Stach et al. 1982), and are possible influences on the reflectance profile at Coal Creek. The sedimentology of the coal measures in the northern Inangahua Valley was previously interpreted in Section 3.3 as representing an alluvial fan deposit, characterised by both rapid sedimentation and syndepositional subsidence. This rapid subsidence and sedimentation resulted in the deposition of an extremely thick coal measure sequence (preserved thickness greater than 1,000m in the Rough/Gorgy Creek area), within a relative short time period (less than 5 million years, using the time scale of Stevens and others 1980).

One possible cause of the marked decline in reflectance above the Wanganui unconformity at Coal Creek could be that the coal measures were initially buried significantly deeper than the preserved stratigraphic thickness suggests, possibly under a high geothermal gradient, with substantial erosion occurring prior to deposition of the Pliocene to lower Pleistocene Giles Formation and Old Man Group.

The cause of the abrupt decline in reflectance above the unconformity at Coal Creek obviously requires more analytical work, in particular a number of proximate analyses from the range of coal types present, to clarify the controls on vitrinite reflectance in these low rank coals. The effects of time, and the possibility of variation in geothermal gradients with time may complicate the coalification history, hence reflectance, of organic material within the Inangahua Valley.

Hypothesis 2: The alternative hypothesis presented is that coal type is an important control on vitrinite reflectance. Recent research by Newman J. and Newman N. (1982), and Newman J. (1985 and 1986) on West Coast Paparoa (Cretaceous) and Brunner (Eocene) coals has shown that paleoenvironmental influences on coal type can cause significant isorank variations in vitrinite chemistry, and hence influence coal properties such as vitrinite reflectance, volatile matter and fluidity within these vitrinite rich coals.

Each of the coal types recognised at Coal Creek are encompassed within a coal type envelope (Figure 6.20), and all coal types are defined in Section 6.3 except:

(a) carbominerites (sample with 20-60% by volume of mineral matter), and
(b) "other coal type", which refers to a coal which is not readily classified into one of the coal type categories.

Each coal type generally has a limited reflectance variation, regardless of changes in depth of burial. For example, carbominerite samples maintain a relatively constant reflectance of approximately $\tilde{R}o=0.29\%$, even though there is approximately 650m between the upper and lower samples within this type grouping. The lack of variation in reflectance between samples of approximately equal type, and the generally poor correlation between reflectance and depth, suggests that coal type is a major influence on reflectance within Rotokohu coals. The vertical reflectance profile within the coal measures at Coal Creek is therefore interpreted as primarily resulting from changing peat swamp conditions on a prograding parallic humid alluvial fan.

Four further samples from the Thomson Member at Rough Creek (Figure 6.20 inset) also suggest a type influence on vitrinite reflectance, because the single Type Co coal sample has higher reflectance than the moderate to low reflecting Type AB coals at this locality. Serial samples at Giles Creek (Figures 6.21 and 6.23) show that Type D coal ($\bar{R}o$=0.36%; interpreted in Section 6.3 to represent relatively well drained swamps) has a distinctly higher reflectance than Type AB coal ($\bar{R}o$=0.30%; poorly drained swamps; Section 6.3), indicating that a strong isorank type influence on vitrinite reflectance can occur in Rotokohu coals.

Newman J. and Newman N. (1982), and Newman J. (1985 and 1986) related type induced variations in vitrinite chemistry of West Coast coals to different levels of peat oxygenation, and/or a variable marine influence. Greater oxygenation results in more aerobic conditions inducing greater degradation within the peatigenic layer, producing relatively hydrogen poor vitrinites with low volatile matter yields and high reflectance relative to coal which formed in more anaerobic swamp conditions (Stach et al. 1982). Greater peat swamp oxygenation may result from:

a) good circulation of the swamp water, with oxygen continually supplied via "fresh" water, or
b) a periodic low swamp water table, which allows limited access of oxygen to the peat.

A variable marine influence can also produce a distinct type related variation in vitrinite reflectance and volatile matter (Newman J. 1985), with a greater marine influence (i.e. more alkaline conditions) resulting in relatively perhydrous vitrinites. Both differences in peat oxygenation and a variable marine influence are possible controls on vitrinite reflectance in Rotokohu coals, given the parallic paleoenvironmental setting inferred from the lithostratigraphy, and the strong type control noted earlier.

The distinct difference in reflectance between Type AB coal at Rough ($\bar{R}o$=0.32-.35%) and Coal ($\bar{R}o$=0.35-.39%) Creeks may therefore result from:

a) particularly poor swamp drainage in the east,
b) a greater marine influence in this area (or a combination of both a and b), or
c) lateral rank variation.

The affect of any true rank variation on vitrinite reflectance between samples from the base of the coal measures in the northern Inangahua Valley is difficult to assess from the data available (i.e. outcrop samples), but nevertheless is a possible control on the lateral reflectance distribution.

A thicker sequence of coal measures is preserved in the upper Rough/Gorgy Creek area relative to Coal Creek, but this does not necessarily reflect an original depositional thickness variation, as the amount of erosion prior to deposition of the Giles Formation at both localities cannot be accurately estimated.

However, the lateral reflectance distribution shown in Figure 6.21 appears to support the hypothesis of coal type variations influencing reflectance, with more perhydrous vitrinites occurring in the east. Sample 11829 from the Gorgy Creek area represents a poorly drained (hence probably perhydrous) Type C coal (Section 6.3, $\bar{R}o$=0.32%), with a similar reflectance to the single Type C coal sample from Coal Creek (sample 11832, $\bar{R}o$=0.30). Type AB coals from the Rough/Ram Creek area have a similarly low reflectance (mostly $\bar{R}o$=0.31-.33) to Type C coals, suggesting more perhydrous vitrinites, probably resulting from either poorer swamp drainage and/or a greater marine influence within Type AB coal in this area. The high reflectance zone in the west from Coal to Thomson Creeks may therefore represent relatively well drained, and/or less marine influenced Type AB swamps relative to those in the east.

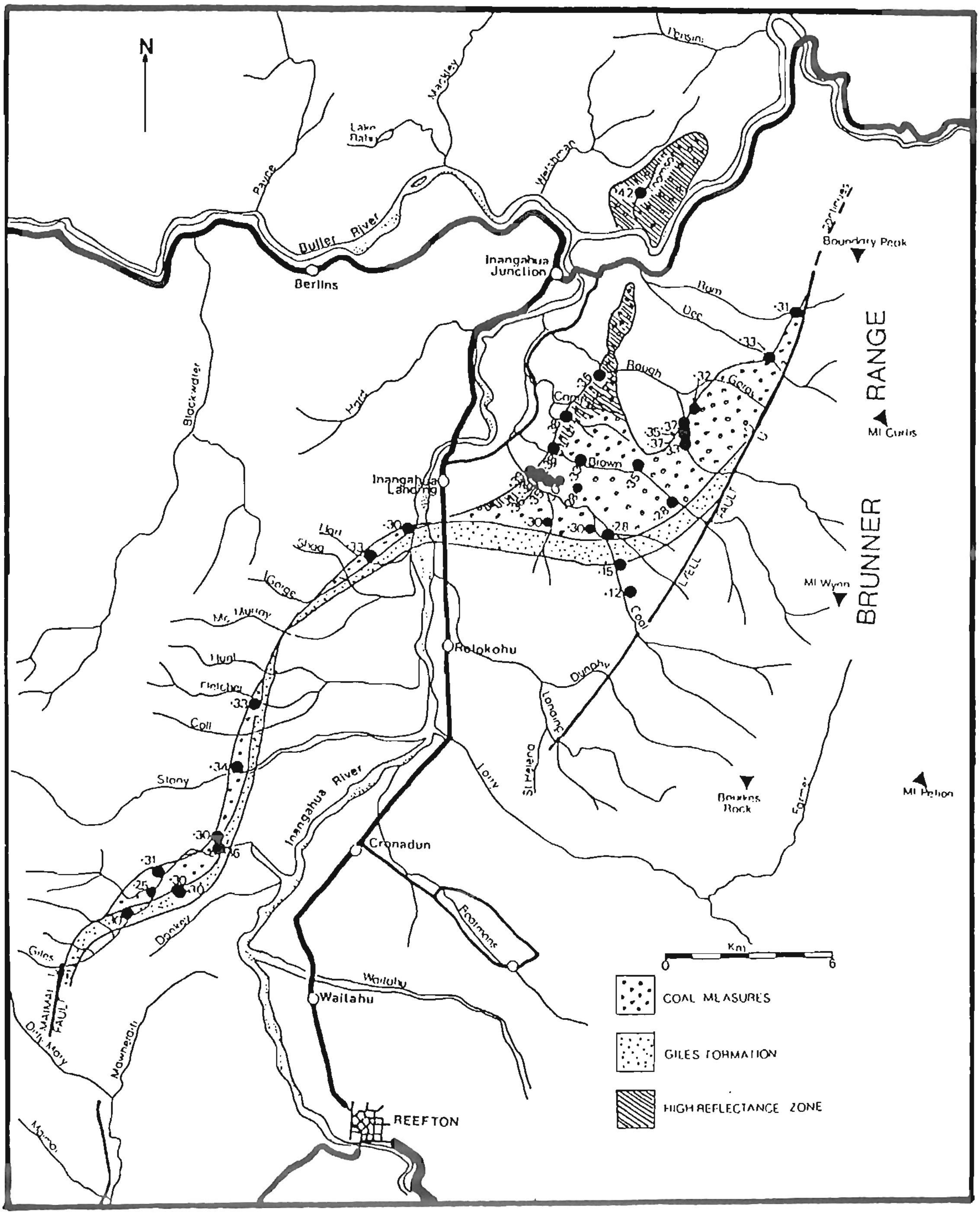


Figure 6.21: Lateral reflectance distribution within the Rotokohu Coal Measures, and three samples from the Giles Formation at Giles Creek.

iii) Conclusions

The Rotokohu Coal Measures in the northern Inangahua Valley were interpreted (Section 3.3) as representing a humid alluvial fan. The limited reflectance variation between samples of broadly similar type at Coal Creek, and the strong isorank reflectance variation at Giles Creek, suggests that the general decline in vitrinite reflectance exhibited by the samples at Coal Creek results primarily from changing peat swamp environments on this prograding alluvial fan, rather than indicating a response to differences in depth of burial.

The major difference in reflectance near the unconformity at Coal Creek may imply significant erosion of the coal measures prior to deposition of the Giles Formation, and/or coalification under different geothermal gradients, but clarification of this hypothesis requires further analytical work.

The lateral reflectance distribution suggests a possible difference in either swamp drainage, and/or a variable marine influence between samples from the base of the coal measures in the west, and those in the east (north of Inangahua Landing), with Type AB coals in the east generally having a similarly low reflectance to poorly drained (hence probably perhydrous) Type C coals from both areas. The effect of lateral rank variation on this reflectance distribution is difficult to assess without drill hole control, but the limited proximate analyses available from outcrop samples also suggest that coals in the east are more perhydrous than those in the west (Section 6.7). Further aspects of vitrinite reflectance are discussed in relation to volatile matter, specific energy, and paleoenvironment in Section 6.6.

6.6 PALEOENVIRONMENTAL INFLUENCE ON COAL PROPERTIES

6.1 Introduction

Much overseas research has highlighted the effects of rank variations on coal properties (e.g. Teichmuller M. and Teichmuller R. 1968a, Stach et al. 1982, Cameron et al. 1984), and the general leaching and/or "retrograde metamorphism" associated with weathering has been appreciated for a number of years (Suggate 1959, Bowen 1964). Paleoenvironmentally induced variations in coal properties have been widely attributed by overseas researchers to aspects of mineral matter and maceral content (Teichmuller M. and Teichmuller R. 1968b, Williams and Ross 1979, Stach et al. 1982), and the processes involved are generally well understood.

Some coal properties such as volatile matter, specific energy, and vitrinite reflectance are known to be affected to varying degrees by paleoenvironmental influences, but in general substantial variations in these properties have been largely regarded as a function of rank.

New Zealand coals have long been regarded as being of an unusual "type" in comparison to most overseas coals (Suggate 1959). Recent research by Newman J. and Newman N. (1982), Newman J. (1985 and 1986), and Newman N. (1985) into the properties of vitrinite rich Cretaceous and Eocene West Coast coals has shown a strong paleoenvironmental influence on many chemical and physical properties within isorank samples, and has demonstrated the need for re-evaluation of the principles commonly applied when assessing the significance of variability in coal properties.

In this section volatile matter, specific energy, and vitrinite reflectance are discussed in terms of possible paleoenvironmental influences on these properties. Once the possible level of paleoenvironmental influence is determined, the coal types previously characterised in Section 6.3 are discussed in terms of their inferred depositional environment based on the relationships between the various physical and chemical data currently available.

The following discussion is limited by two factors discussed previously:

a) All samples discussed in this section are from outcrop (proximate analyses from DH 118 were not received until 31st October 1986, and consequently no petrographic analyses are available for these samples). Weathering must therefore be considered as a probable influence on the proximate and ash constituent analyses determined in this study. Accurately determining the degree of weathering for any given sample is impossible, given the nature of the data (i.e. low rank coal, with no drill hole control).

b) Because the study is primarily a regional appraisal of the Rotokohu Coal Measures, and in view of the expense involved in obtaining proximate analyses, few serial samples are available to give isorank control. However, the general relationships indicated by this study are consistent with those noted in the more detailed work of Newman J. (1985 and 1986), and suggest that similar influences on coal properties may occur in Rotokohu coals.

Further work on samples obtained from DH 118 will provide greater control on both isorank relationships, and the possible effects of weathering on the samples analysed in this thesis, and is strongly recommended.

6.6.2 Coal Type Influence on Volatile Matter, Calorific Value and Vitrinite Reflectance Within Rotokohu Coals

i) Volatile Matter

A strong relationship appears to exist between coal type and the volatile matter yield of Rotokohu coals. A plot of volatile matter (dmm1/2sf) against exinite percentage (mmf) reveals two broad groups (Figure 6.22):

a) a high volatile group (>51%), with a correspondingly high exinite content (>18%), and

b) a lower volatile (<50%), lower exinite (<18%) group.

The high volatile matter group is dominated by Type C "leaf" coals, while the low volatile group is dominated by coal types AB, D and Co. The abundance of hydrogen rich

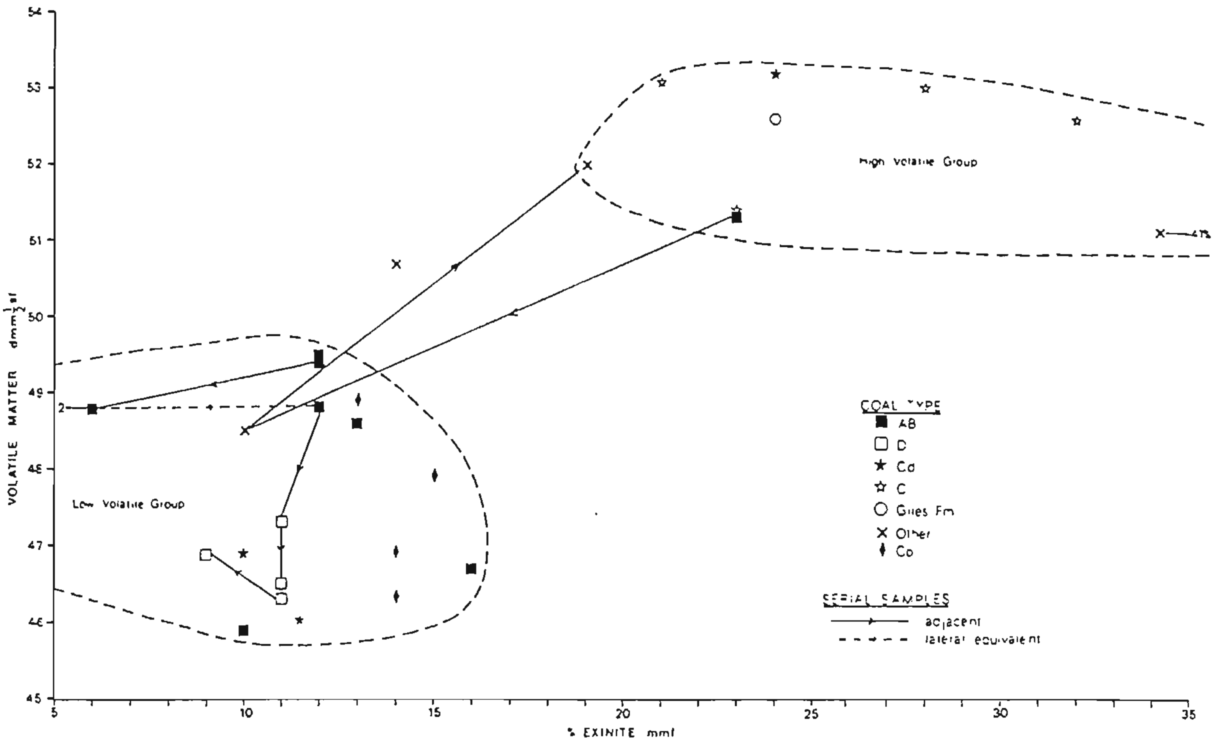


Figure 6.22: Relationship between exinite percentage and volatile matter yield. Serial samples are joined by solid lines. Dashed line=lateral equivalent (i.e. sample taken along strike).

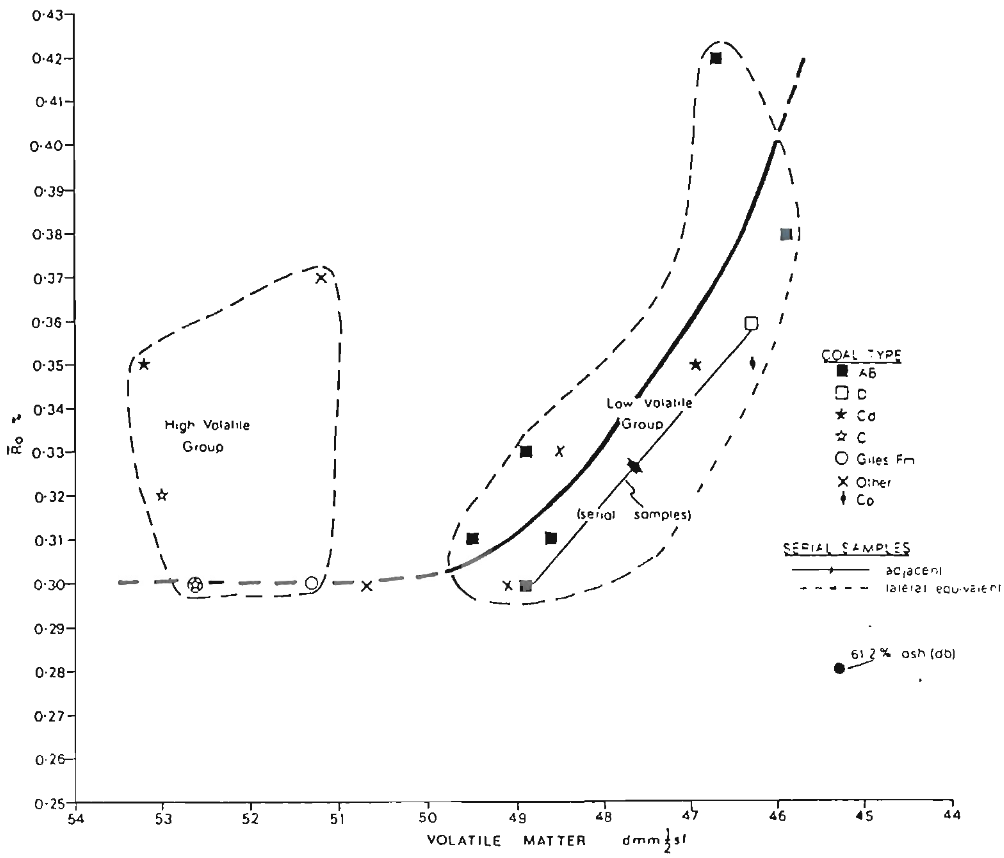


Figure 6.23: Relationship between volatile matter yield and vitrinite reflectance.

exinite macerals cutinite and liptodetrinite is considered the major cause of the elevated volatile matter yield within the high volatile group. Similar relationships between exinite content and volatile matter yield are noted by Black (1981) for reactives rich Miocene aged Taranaki coals, and by Stach et al. (1982) for Devonian to late Tertiary aged European and American "leaf coals".

Isorank samples from the thick seam at Hart Creek exhibit major variations in volatile matter yield (Figure 6.22). These variations are attributed primarily to differences in exinite content between the samples. Isorank serial samples from Giles Creek reveal distinct differences in the volatile matter yield between relatively low exinite coal types AB and D. Most of these samples have a similar exinite content (11-12%), although one relatively high volatile Type AB sample (dominated by the A component, or log aggregates), has an extremely low exinite content. The variation in volatile matter yield between coal types AB and D at Giles Creek is not due to differences in exinite content, and is therefore inferred to represent variations in vitrinite chemistry, with Type AB vitrinites being hydrogen rich (i.e. perhydrous) relative to Type D vitrinites.

As discussed previously in Sections 6.3 and 6.5, Newman J. and Newman N. (1982), and Newman J. (1985, 1986) have attributed isorank variations in vitrinite chemistry to different levels of swamp oxygenation, with more anaerobic peatification commonly producing relatively hydrogen rich vitrinites with depressed reflectance. A similar relationship may also result from a variable marine influence, with a greater marine influence producing a higher volatile matter yield and lower reflectance (Newman J. 1985).

The inverse relationship between volatile matter yield and vitrinite reflectance shown by coal types AB and D at Giles Creek (Figure 6.23), suggests that Type AB coal accumulated in relatively anaerobic and/or more marine influenced peat swamps compared with Type D coals.

Accurate assessment of volatile matter variations due to differences in thermal maturation is extremely difficult given the nature of the data. However, the consistent relationships between the type induced variations noted above suggests that rank and weathering related influences on volatile matter yield may be minimal in comparison to type induced variations in these low rank reactives rich coals.

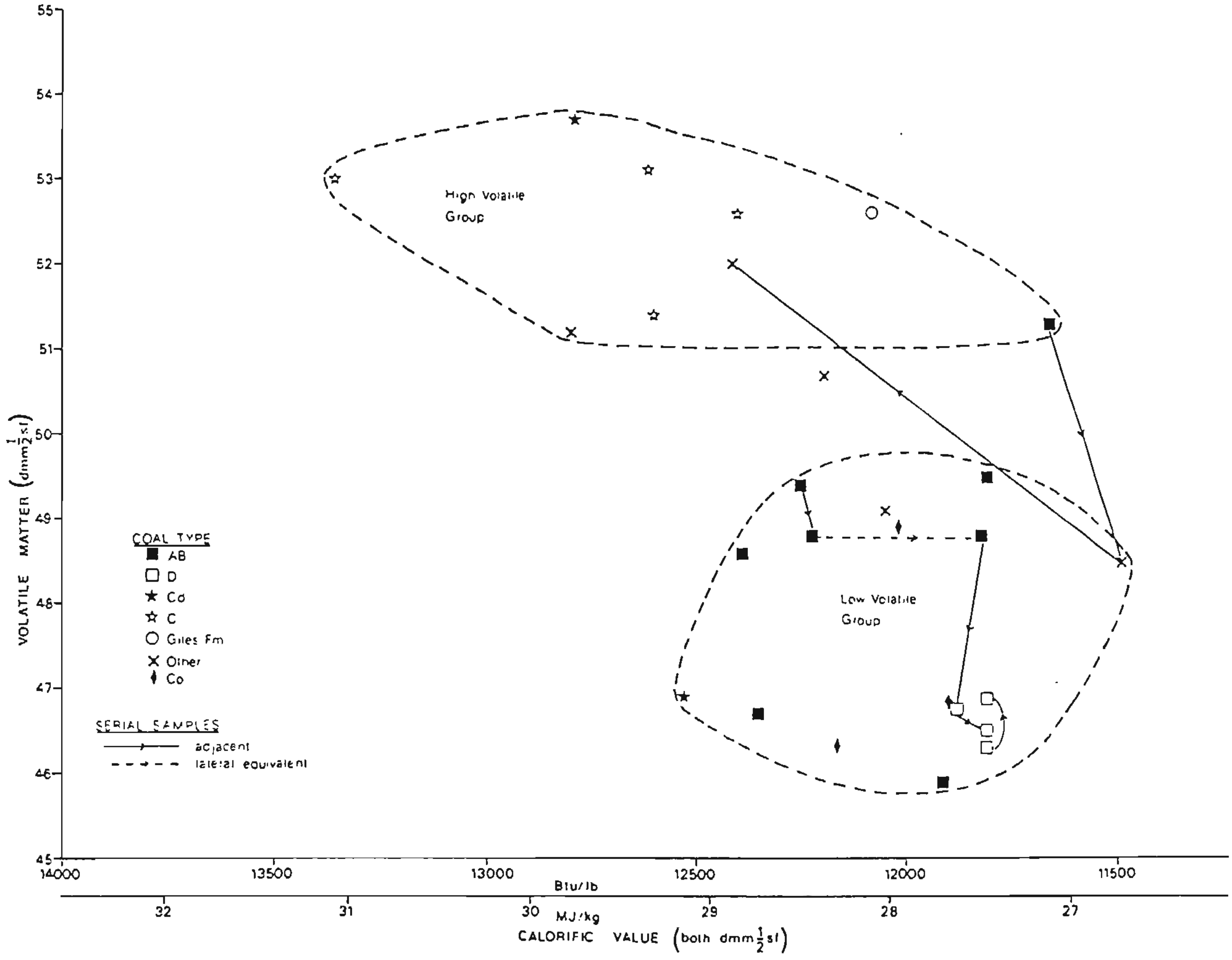
ii) Vitrinite Reflectance

The relationship between vitrinite reflectance and volatile matter is shown in Figure 6.23. Coals within the exinite rich high volatile group do not show a clear relationship, with the volatile matter yield in these samples predominantly controlled by the high exinite content. The low exinite/low volatile matter group shows a broad inverse relationship between volatile matter and vitrinite reflectance, and substantial isorank variation between serial samples of coal types AB and D at Giles Creek.

The strong type control on vitrinite reflectance noted above, supports the observations of McCartney and Teichmuller M. (1972) that vitrinite reflectance and volatile matter yield are not useful measures of thermal maturation in low rank coals (i.e. coals less than medium volatile bituminous rank). Recent overseas research (Cameron et al. 1984, Parkash et al. 1984) has suggested that both vitrinite reflectance and volatile matter are useful rank parameters in low rank coals (sub bituminous to lignite A ranks). The above discussion suggests such assumptions are erroneous in reactives rich Rotokohu coals, where significant type control is exerted on both volatile matter yield and vitrinite reflectance.

iii) Calorific Value

The relationship between exinite content and calorific value (dmml/2sf) shown in Figure 6.24 is less distinct than the volatile matter/exinite relationship noted previously, although a strong isorank variation is still evident. Serial samples from Hart Creek have a greater isorank variation in calorific value than low exinite Giles Creek samples, indicating that exinite content has a strong influence on calo-



<u>Figure 6.24</u>: Relationship between exinite and calorific value. High and low volatile groups correspond to exinite rich and poor groups determined in Figure 6.22.

rific value in Rotokohu coals.

The positive correlation between exinite content and calorific value is relatively well understood, and documented within the literature (Suggate 1959, Bowen 1964, Black 1981, Stach et al. 1982). Isorank low exinite samples from Giles Creek indicate that type induced variations in vitrinite chemistry can also produce significant variation in calorific value (up to 1.15 MJ/kg). This paleoenvironmentally induced variability in calorific value is not widely recognised by overseas researchers, but is consistent with the inverse relationship noted previously between vitrinite reflectance and volatile matter, both of which were attributed to variations in peat swamp oxygenation, and/or a variable marine influence.

iv) Conclusions

Greater oxygenation and/or less marine influence during peatification in Rotokohu coals is inferred to result in higher reflectance, lower volatile matter yields, and lower calorific values than more anaerobic and/or marine influenced peatification which produced relatively perhydrous vitrinites with lower reflectance, higher volatile matter yields and generally higher calorific values. Volatile matter yields and calorific value are also strongly influenced by exinite content, which is controlled by coal type.

Both weathering and rank induced variations in these coal properties appear to be minimal in comparison to the consistent paleoenvironmentally induced variations noted above, but nevertheless must still be considered as a probable influence on the analytical properties of the samples used in this thesis.

6.6.3 Paleoenvironmental Significance of Coal Types

All coal seams analysed from the Rotokohu Coal Measures are inertinite poor, suggesting wet swamp conditions.

i) Type AB

Type AB coal is inferred to represent poorly drained, marine influenced, hypautochthonous to in part allochthonous peat swamps. A relatively "alkaline" or marine influence is inferred for Type AB coal from:

a) the restricted stratigraphic distribution of Type AB coal at the base of the coal measures. (Type AB coal is the dominant coal type within the marine influenced Thomson Member [Section 3.3], and in the thick basal seam of the Donkey Member, both of which conformably overlie the shallow marine Ram Creek Member.)

b) the occurrence of significant tissue degradation within the B component, despite the relatively high water level inferred for Type AB swamps on other grounds (i.e. frequent clastic partings, and perhydrous vitrinites [also possibly due to a greater marine influence relative to other coal types]).

c) the recent discovery of marine dinoflagellates within thick Type AB coal at Giles Creek, and in all pollen samples collected form the Thomson Member (associated with Type AB coal) at Coal Creek (Mildenhall, pers. comm.)

Evidence for a high water table in Type AB swamps discussed previously (Sections 6.3 and 6.6), is inferred to have resulted in a restricted oxygen supply during peatification, which in association with a marine influence resulted in perhydrous vitrinites with characteristic high volatile yields and low reflectance relative to Type D vitrinites. The relatively common occurrence of early stage micrinite (fine, granular, high reflecting bodies; Figure 6.25) within Type AB coal may also be suggestive of perhydrous conditions. Stach et al. (1982) note that similar "type" related micrinite in low rank coals is noticeably hydrogen rich, and is commonly considered to form preferentially in anaerobic swamp conditions.

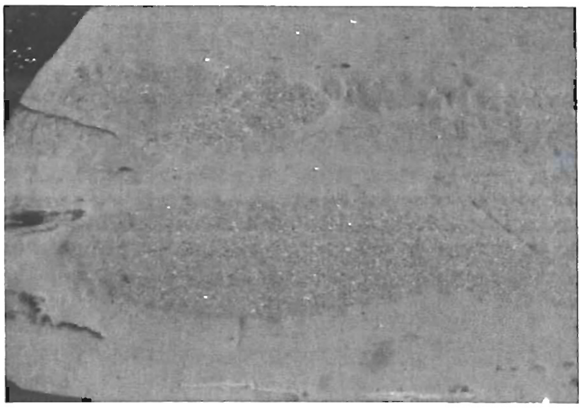


Figure 6.25: Fine, high reflecting "early stage" micrinite within resinous cell infillings in A component (ie. log, sample 11812).

Variations in both the degree of marine influence, and/or swamp oxygenation within Type AB coals is the probable cause of the variation in reflectance between Type AB coals at the base of the coal measures in the northern Inangahua Valley (Figure 6.21). This variability suggests that the type classification is rather broad, being primarily based on the variable (although generally high) ash content, moderate to low TPI where log aggregates are absent (generally 0.3-0.5%), moderate exinite content (generally 10-15%, and dominated by liptodetrinite) and high volatile matter yield (where proximate analyses are available).

Type AB coal in the north-west (Coal/Camp Creek area) may represent well drained and less marine influenced swamps, producing a high reflectance relative to Type AB coal in the east (upper Rough/Ram Creek). Poor drainage in Type AB swamps at the base of the coal measures may have allowed a greater marine influence in the east, thus the two effects could combine to produce perhydrous vitrinites, and this is inferred to be the probably cause of the low reflectance in the north-eastern Inangahua Valley.

An alkaline swamp environment can promote bleaching/corrosion of exinite macerals (Stach 1968, Diessel pers. comm.), if oxygen is available (Newman J. per. comm.). The restricted oxygen supply within the marine influenced Type AB swamp environment is inferred to have generally inhibited the chemical bleaching of exinite macerals, and resulted in relatively dark exinites in comparison to Type D coals.

Tissue preservation (TPI) within Type AB swamps was generally poor, but the presence of hypautochthonous to possibly allochthonous logs results in variable TPI contents. High swamp water levels generally result in relatively good preservation of macerals by inhibiting aerobic microorganisms (Stach et al. 1982, Newman J. 1985). In Type AB coals the highest water levels are inferred to be associated with log accumulations and clastic partings. The clarain rich B component has a low to moderate TPI (generally 0.3-0.5), and a variable ash content. The relatively high level of tissue degradation in the B component is inferred to probably result from the marine influence.

A marine influence is commonly attributed to greater biochemical tissue degradation, and/or lower tissue preservation through:

a) a greater incidence of herbaceous plants within the swamp flora (Teichmuller M. and Teichmuller R. 1968b, Stach et al. 1982, Newman J. 1985 and 1986),
b) a higher swamp pH, which encourages greater bacterial activity.

Microlithotype analyses suggest a slightly higher herbaceous component to the swamp flora in Type AB coal, although the applicability of this technique to coals of limited maceral group composition (such as most vitrinite rich New Zealand coals) is questionable.

Relatively high sclerotinite values are characteristic of the desmocollinite rich B component of Type AB coal (Figure 6.26). This association may imply a larger reed moor component within the swamp flora, as some fungi grow preferentially in association with grasses (Teichmuller M. and Teichmuller R. 1968b, Stach et al. 1982). However, such an association may also result from concentration of sclerotinite due to selective decomposition of less resistant plant tissues (Stach et al. 1982). Either mechanism is a possible cause of relatively high sclerotinite contents, given the marine influenced hypautochthonous environment of deposition inferred for Type AB coal.

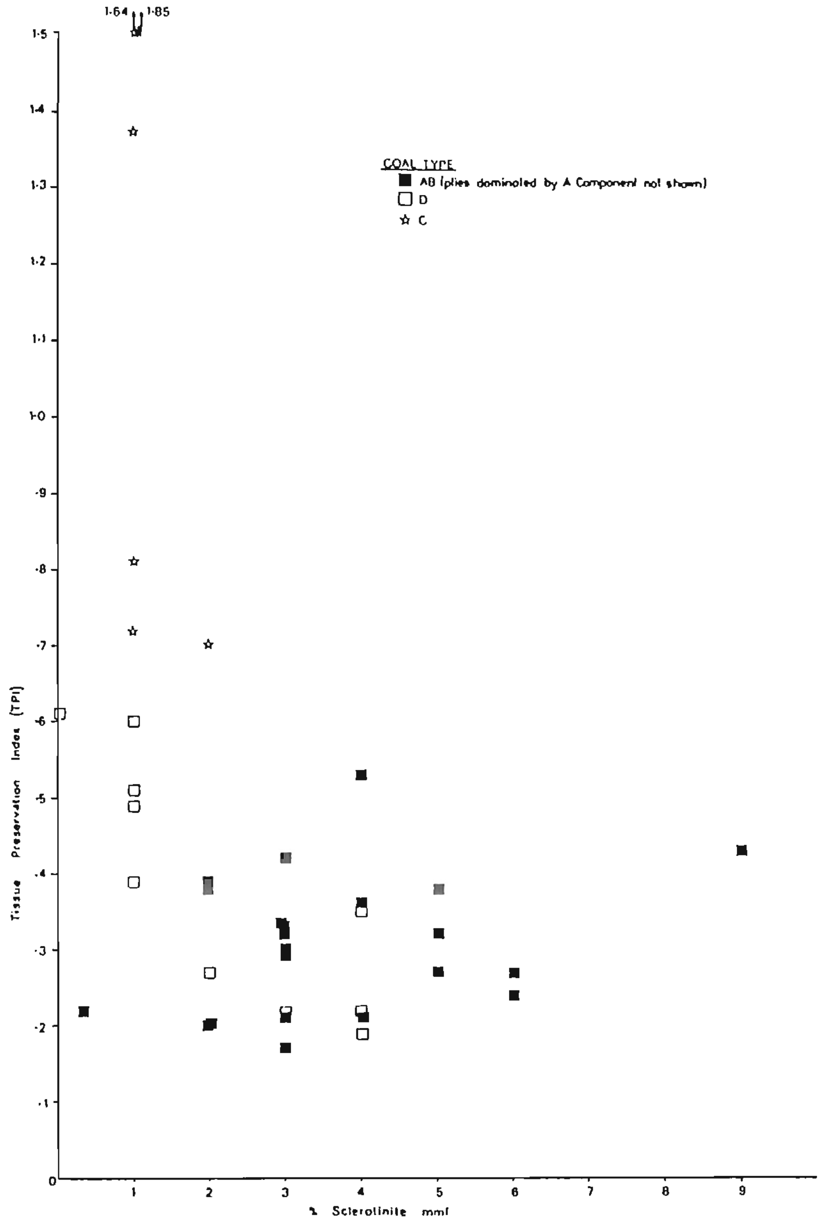


Figure 6.26: Relationship between T.P.I. and sclerotinite abundance. Type AB coal samples dominated by logs (i.e. the A component) are not shown.

ii) Type D

Type D coal is inferred to represent relatively well drained, autochthonous to possible hypautochthonous peat swamps. The low to very low ash content (generally <4% db, and commonly <3% db) suggests better swamp drainage than most Rotokohu coal types. The lower water table is inferred to have allowed greater oxygenation during peatification, and resulted in the characteristically low volatile matter yields, calorific value, and higher reflectance for Type D coal relative to Type AB coal. The characteristic moderate to low TPI (0.3-0.5) of Type D coal is also consistent with deposition in an oxygenated swamp, with a relatively high level of tissue degradation.

Although Type D swamps are inferred to have been relatively well drained, they never became "dry", and consequently like all Rotokohu coals are poor in inertinite (<6%). Similar wet but "well drained" swamp models have been proposed by Newman J. (pers. comm.) for some West Coast coals, with oxygenated water continually moving down through the peat, resulting in relatively hydrogen poor vitrinites with high reflectance and low volatile matter.

Bleached exinites are suggestive of an oxygenated paleoenvironmental setting, and the bleaching and/or loss of exinites was also noted by Newman J. (pers. comm.) in her wet "raised swamp" model, suggesting that the exinites are unstable in this paleoenvironmental setting. This may imply severe leaching within the swamp, although mineral matter studies of Type D coals did not indicate the presence of aluminium hydroxides which are reported from "leached swamps" in the Buller Coalfield (Newman N. 1985).

The relatively high suberinite content of Type D coal results from distinctive stem/root cross-sections. These would have been particularly resistant to decay (Stach et al. 1982), and may represent either autochthonous, or hypautochthonous peat accumulations. The relative abundance of vitrodetrinite is usually considered suggestive of hypautochthonous peat accumulation, although the autochthonous generation of vitrodetrinite is also possible through greater oxygenation inducing decay of the plant tissue, and is probably more consistent with the low water level in Type D swamps.

A similar correlation between suberinite and vitrodetrinite was noted by Newman J. (1985) for Brunner Coal at Pike River, and was inferred to have been derived from a herbaceous flora. However, microlithotype analysis suggests that Type D coal is derived from a distinctly "woody" flora, with almost no A-or D-microlithotype components.

iii) Type C

Type C coal is inferred to represent leaf accumulations within poorly drained low energy overbank settings. The high TPI, resulting from the characteristic layering of abundant telocollinite and well preserved cutinite macerals, was interpreted in Section 6.3 as suggesting a high water level, yet " low energy" swamp with very little mechanical or biochemical degradation of organic material. The variable ash content (3.9-13.4% db), concentration of the mineral matter in discrete layers, and the strong clastic mineral matter component indicated by most ash analyses also suggest a high water table. The very low inertinite content of Type C coals also suggests a consistently high, probably stagnant water table.

The high water table is inferred to have produced perhydrous vitrinites, which in combination with the high exinite content results in an extremely high volatile matter yield for Type C coals (>51%), yet a generally low vitrinite reflectance ($\bar{R}o$=0.30-.32%).

iv) Type Cd Type Cd coal is inferred to represent leaf accumulations within a higher energy environment relative to Type C peat swamps. The high clastic ash content and high TPI were interpreted (Section 6 3) as consistent with a high water table, and the characteristically high liptodetrinite content suggests a greater degree of mechanical and/or biological degradation relative to Type C swamps.

The variable volatile matter yields are attributed primarily to variations in exinite content, although the high ash values make correction of volatile matter for the contribution by mineral matter less reliable. Vitrinite reflectance is usually moderate (i.e. approximately $\bar{R}o$=0.35%), indicating that Type Cd swamps were more oxygenated than Type C swamps. The oxygen supply is inferred to have been maintained by either:

a) oxygen bearing water flowing through the peat swamp, or

b) fluctuating swamp water levels, with periodic high water levels introducing clastic mineral matter and reworking the peat.

Both mechanisms are possible causes of the high ash/moderately high reflecting (i.e. oxygen rich, relative to Type C coals) Type Cd coals.

v) Type Co

Type Co coal is inferred to represent better drained swamps relative to Type AB, C and Cd swamps. The low TPI (always <0.5, and commonly <0.3) and moderate ash content (4.7-7.5% db), were previously interpreted (Section 6.3) as suggesting good swamp drainage relative to Type C and Cd coal. The low volatile matter yield of Type Co coal is interpreted as resulting from both the low exinite content (<15%), and oxygen rich vitrinites which resulted from relatively good swamp drainage. The limited reflectance data available suggests a high reflectance relative to Type C and Cd coals and is consistent with relatively well drained, hence oxygenated swamps.

6.7 RANK ASSESSMENT IN THE ROTOKOHU COAL MEASURES

6.7.1 Introduction

Fundamental chemical, physical and petrographic changes occur within coal during the process of coalification. These changes are considered by most geologists to primarily result from temperature increases induced during increased burial (Teichmuller M. and Teichmuller R. 1968a, Stach et al. 1982). The broad responses of coal properties to increasing coalification form the basis of rank classification schemes (Figure 6.27). A complete discussion on rank theory is beyond the scope of this thesis and the interested reader is referred to more detailed works by Suggate (1959), Teichmuller M. and Teichmuller R. (1968a), and Stach et al. (1982), for an outline of the various effects of increasing rank on coal properties.

The parameters used in rank classification include moisture (commonly bed moisture in low ranks), calorific value, volatile matter, fixed carbon and vitrinite reflectance. Paleoenvironmental influences on these properties (excluding moisture) are inferred to be significant within reactives rich Rotokohu coals, therefore rank assessment must be undertaken with considerable caution. The following discussion is included to supplement aspects of coal geology discussed in previous sections and is not intended as a detail discussion of rank assessment within low rank coals.

6.7.2 ASTM Rank Classification

ASTM standard D388-77 "Standard method for the classification of coals by rank", classifies Lignite A and sub bituminous coals on the basis of their bed moisture, and moist ash-free calorific value (Bowen 1978, Gray 1983). Bed moisture is the equivalent of inherent moisture present within the coal in ground, when the coal is in an equilibrium state (modified after Bowen 1978).

Bed moisture, or approximations to bed moisture, are commonly used in assessing the moist, ash-free calorific value of low rank coal. Air-dried moisture values do not approximate bed moisture for coals with greater than 18% air-dried moisture (at 70% relative humidity and 20 degrees Celsius; Suggate 1959, Bowen 1978, Gray 1983). Bowen (1978) proposed a modified version of the ASTM classification system be adopted in New Zealand, and his system is commonly used by officers of the New Zealand Geological Survey.

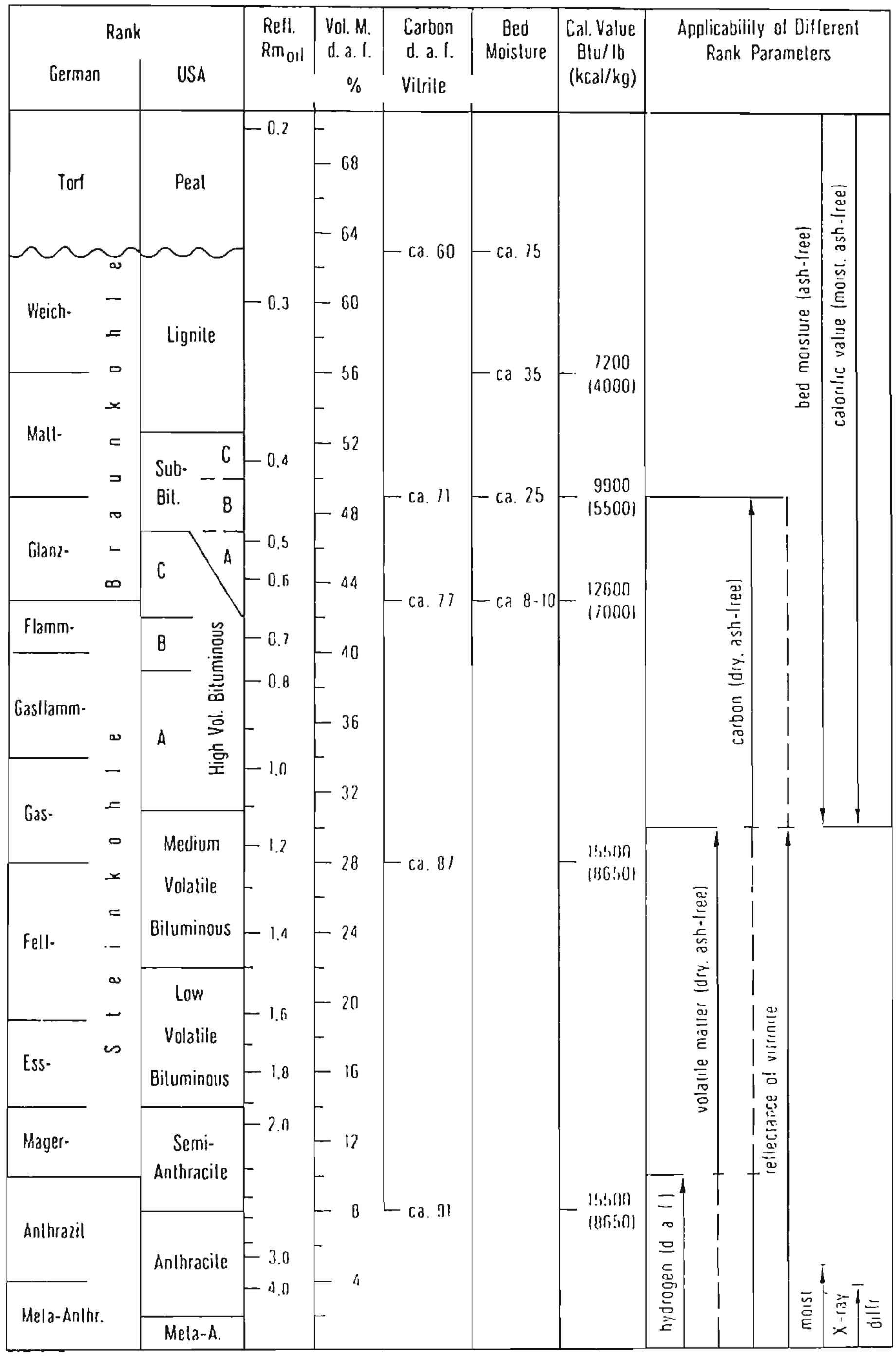


Figure 6.27: The different stages of coalification according to German (DIN) and American (ASTM) classifications, and distinction on the basis of different physical and chemical parameters. The last column shows the applicability of various rank parameters to the different coalification stages (from Stach et al. 1982).

Nathan (1978a) classified the Rotokohu Coal Measures as sub bituminous C and B using ASTM classification. Because the samples used by Nathan were outcrop and mine samples, the reliability of the bed moisture values is questionable, and the ranks assigned by Nathan are probably fractionally high.

Samples from DH 118 provide the most reliable approximations to bed moisture values for Rotokohu coals. Total moisture values for these samples range from 22.2-34.3% (determined by oven drying by CRA), and most samples are around 26-30%. These values are higher than all previously measured values determined from outcrop samples, and generally indicate a low sub bituminous C rank (ASTM classification) for Rotokohu coal at Giles Creek.

In view of the significant type influence on calorific value noted previously, this rank classification must be treated cautiously. Volatile matter variations between samples from DH 118 suggest a degree of type variation, and it is recommended that these samples receive full petrographic analyses (i.e. maceral analysis, vitrinite reflectance, and fluorescence). These analyses should enable a better understanding of the relationship between coal type and important coal properties in Rotokohu coals, and will be relevant to other reactive rich coals of similar rank, such as the Miocene coals of the Taranaki region.

6.7.3 Suggate Rank

The rank classification proposed by Suggate in 1959 attempted to define the "degree of coalification" in terms of volatile matter and specific energy (both dry, mineral matter and sulphur free basis), with allowances made within the scheme for coal type variation. Suggate Rank (Rank S) has recently been the subject of some controversy, particularly with regard to the principal assumption within the scheme of colinearity between proportions of carbon and hydrogen in isorank samples of varying type (Newman J. and Newman N. 1982).

Note:

(1) Rank S uses full sulphur in correction formulas for both volatile matter and calorific value (Suggate 1959, p72-73), while the formula used in all corrections in this thesis, except in the Rank S diagram, is that proposed by Newman N.A. 1985, using half sulphur values in the numerator.

(2) Isorank lines used in Figure 6.28 are those used by Suggate and Lowery 1981. The implications of CRA's change to the British Standard method for proximate analysis in 1982 to the Suggate Rank diagram is considered beyond the scope of this thesis. The interested reader is referred to Newman J. and Newman N. (1982 and 1983) for a discussion on possible modifications to the Rank S diagram.

The correction for moisture makes Rank S superficially attractive for use with low rank sub bituminous coals such as Rotokohu coals, where reliable bed moisture values are not available. However, volatile matter yields and calorific value are inferred to have a strong type control in Rotokohu coals, and Rank S is clearly affected by this type variation (Figure 6.28).

Serial (hence isorank) samples from Hart Creek show a large variation in Rank S (approximately 3.9-5.5; or 1.5 rank numbers), which is primarily attributed to variations in exinite content (Section 6.6). Isorank variations in vitrinite chemistry between serial samples at Giles Creek result in a Rank S variation of almost 1 rank number (approximately 5.2-6.1). These variations support the prediction of Newman J. and Newman N. (1982 and 1983), that isorank variation in both vitrinite chemistry and exinite can significantly influence the Rank S of coal samples.

Figure 6.29 shows the lateral distribution of Suggate Rank numbers for all outcrop samples collected during this MSc investigation, with exinite rich (>18%) and poor <18%) samples differentiated. The highest values within low exinite coals occur at Giles Creek (6.1), and in the north-north-east at Brown (7.1), Rough (6.2) and Ram (6.6) Creeks,

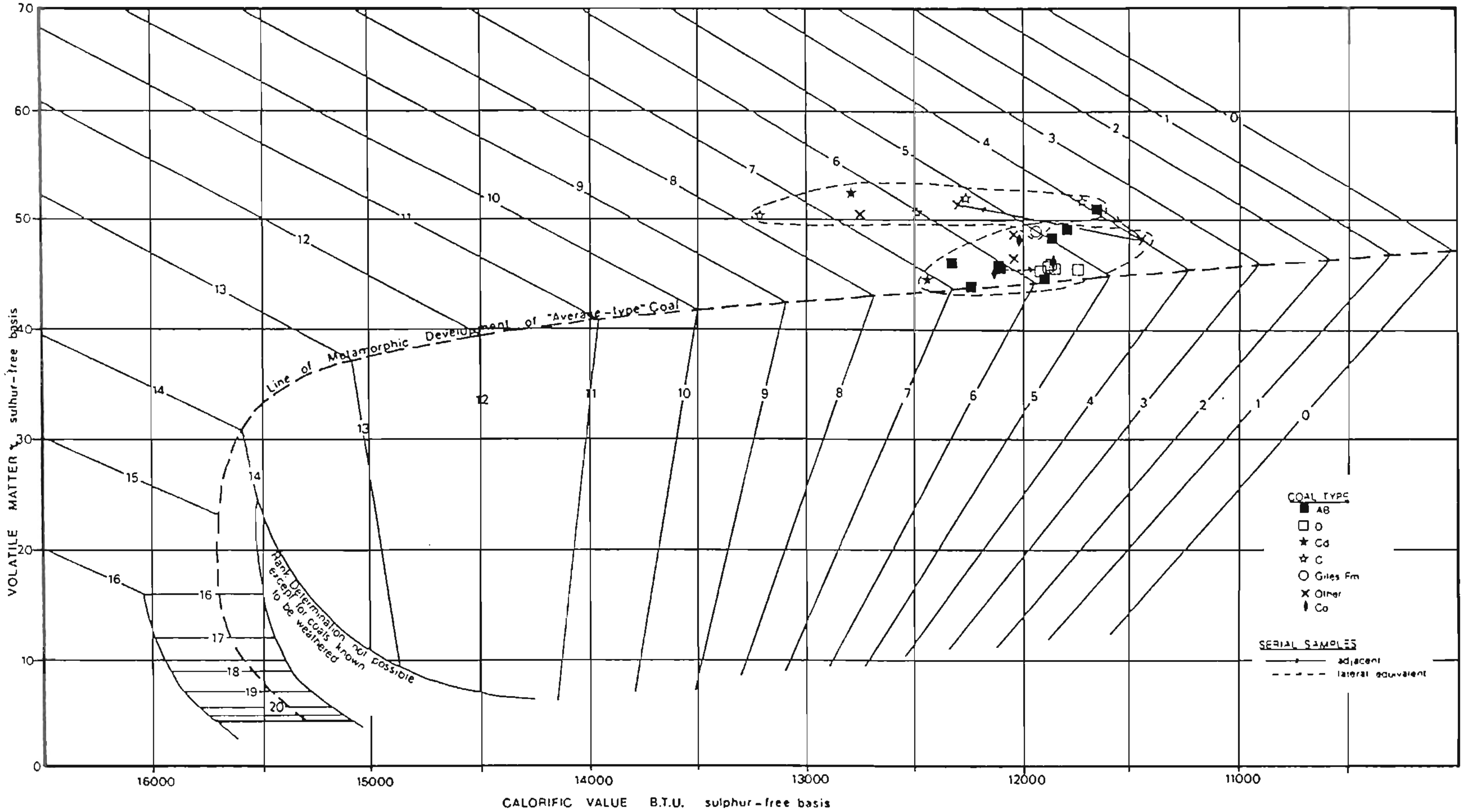


Figure 6.28: Rotokohu coals and a single Giles Formation coal plotted on a Suggate Rank diagram (diagram from Suggate and Lowery 1981). Serial samples of varying exinite content from Hart Creek are joined by arrows. Two fields shown correspond to high (exinite rich) and low (exinite poor) volatile groups defined in Figure 6.22.

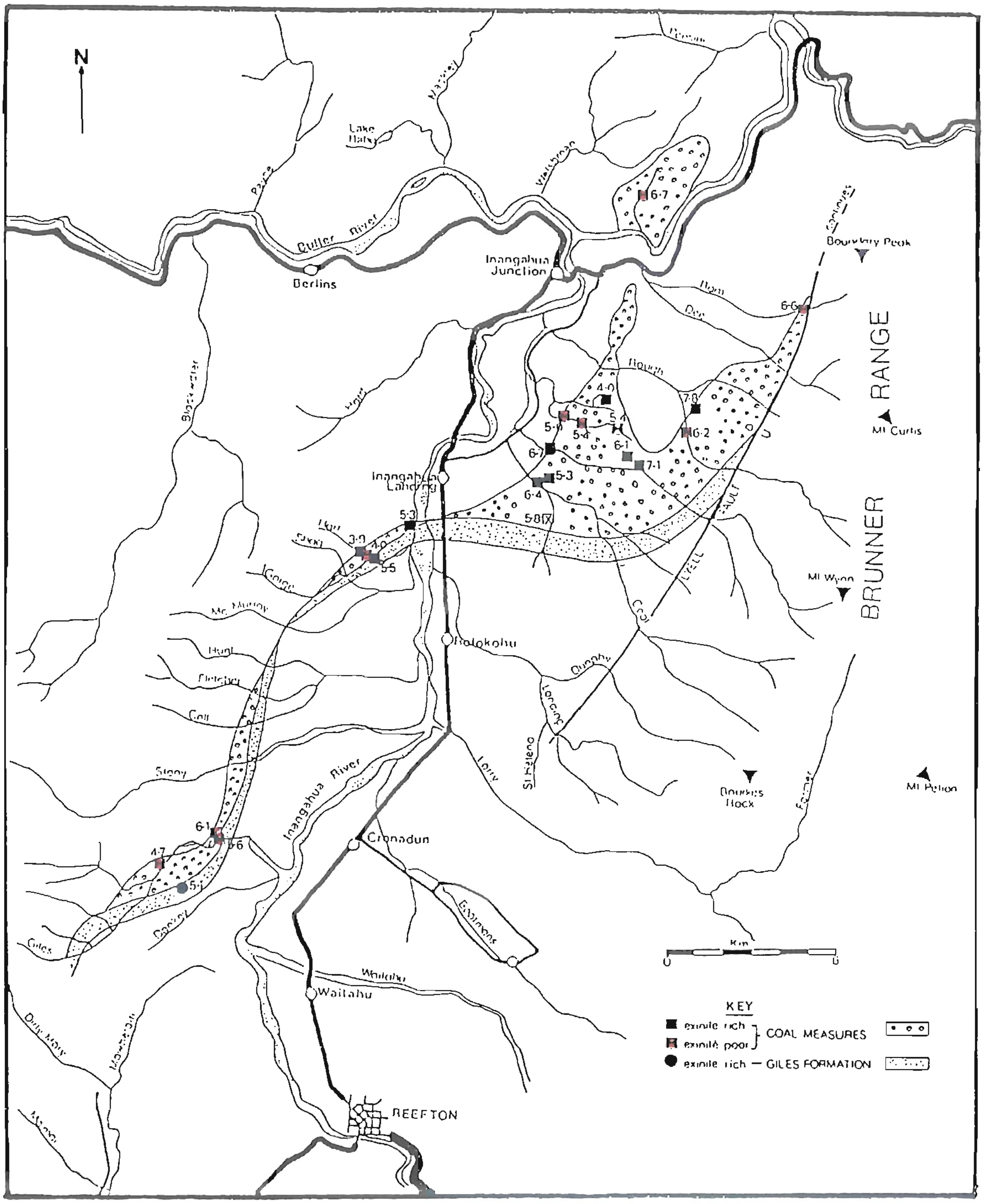


Figure 6.29: Lateral distribution of Suggate Rank numbers in Rotokohu coals and a single Giles Formation coal. Exinite rich (>18% exinite) and poor (<18%) samples are distinguished.

and in the north at Thomson Creek (6.7). Samples collected by Nathan S. in 1969 also suggested a north-north-easterly increase in Suggate Rank (Nathan pers. comm.).

More research is needed to clarify the controls on both Rank S and reflectance in the Rotokohu Coal Measures. However, the north-north-easterly increase in Suggate Rank (within low exinite samples), yet low reflectance of Type AB coals in this area (relative to the Coal/Camp Creek area), is consistent with a north-north-east change to more perhydrous coals. These would have relatively low reflectance and high volatile matter yields/calorific value, resulting from less oxygenation of the peat swamps and/or a greater marine influence compared with coals in the Coal/Camp Creek area.

Newman J. and Newman N. (1982) infer that vitrinite chemistry can vary between isorank samples, hence state that

> "isorank coals of apparently similar type, in the simplest sense of maceral group proportions, could have significantly different chemical analyses."

The broad inverse relationship between vitrinite reflectance and Rank S within low exinite Type AB coals at the base of the coal measures may therefore represent variations in vitrinite chemistry within coals of broadly similar type, perhaps indicating greater syndepositional subsidence in the north-north-east, inducing poor swamp drainage and/or an increased marine influence on a regional scale relative to swamps in the west.

The effects of any possible lateral rank variation, and/or variation in weathering may also be factors influencing the limited number of proximate analyses available. However, the similarity between the Rank S trends indicated by samples collected by Nathan 1969, and samples collected in this thesis suggests weathering may not be a major influence on the proximate analyses.

6.7.4 <u>Summary</u>

Most rank classification schemes for low rank coals are based on moist calorific values (e.g. ASTM; Economic Commission for Europe Classification; Australian Standards Association; see Gray 1983 for a general discussion on classification systems), with the moisture value generally an approximation to bed moisture. Reliable bed moisture values are generally only satisfactorily obtained from suitably handled drill core samples (i.e. drill core samples where care is taken to preserve the original in-ground moisture). Within the Rotokohu Coal Measures such samples are only available for Dh 118.

The parameters commonly used for rank assessment, i.e. volatile matter, calorific value and vitrinite reflectance, are all influenced to varying degrees by coal type within Rotokohu coals. Exinite content is a major influence on both volatile matter yield and calorific value, while paleoenvironmental influences on vitrinite chemistry are inferred to effect volatile matter yield, calorific value and vitrinite reflectance. Consequently the application of rank schemes based on these three parameters is complicated by variations in coal type.

Samples used for comparing thermal maturation must ideally have identical maceral proportions, and have had identical levels of peat oxygenation. Determining these parameters is extremely difficult, and requires extensive analytical work, integrated with depositional models of peat accumulation based on lithostratigraphic and petrographic data. The samples from DH 118, for which bed moisture values are available, have not received petrographic analyses, and consequently no adjustment can be made for coal type influences (coal type influences are suggested by in-seam variations in volatile matter yield between plies analysed from this drill hole).

Rank assessment in the Rotokohu Coal Measures based on all available data suggests a relatively higher rank north of Inangahua Landing than in the south, and is consistent with the preserved thickness of coal measures which is much greater in the north. Different levels of peat swamp oxygenation, a variable marine influence, variations in exinite content, and possible variations in rank and the degree of weathering, produce complicated patterns of Rank S and vitrinite reflectance. Thus, further clarification of rank variation is extremely difficult.

In conclusion, the relationships outlined previously between volatile matter, calorific value, vitrinite reflectance and paleoenvironment are at best general, but nevertheless consistent with relationships suggested from more detailed work by Newman J. (1985) for Eocene Brunner and Cretaceous Paparoa coals, and more general work on Miocene Taranaki coals (Black 1981). Further clarification of the relationships between bed moisture, volatile matter, calorific value, vitrinite reflectance, paleoenvironment and coal rank, in reactives rich Rotokohu coals will require more detailed investigation of coal petrology and chemistry, using drill hole samples (wherever possible).

CHAPTER SEVEN

SYNTHESIS OF GEOLOGY

7.1 A DEPOSITIONAL MODEL FOR THE ROTOKOHU COAL MEASURES

7.1.1 Regional Paleogeographic setting

The early to late Miocene Rotokohu Coal Measures are inferred to represent a parallic, humid fan-delta sequence (a fan-delta is defined as an alluvial fan that progrades into a standing body of water; Westcott et al. 1980). Provenance studies of conglomerate clasts from the Rotokohu Coal Measures (Inangahua Valley; Wellman et al. 1981, Nathan 1978a, Nathan and others 1986, Chapter 2), and Longford Formation/ Rappahannock Group (Murchison/Maruia Valleys; Cutten 1979, Watters 1982, Nathan and others 1986), indicate separate source areas for these non-marine, early to late? Miocene sequences (Figure 7.1). (Note: the top of the Longford Formation is not preserved, and reliable dates are not available for the preserved upper Longford Formation, or its probable lateral equivalent in the Maruia basin, the Rappahannock Group; Nathan and others 1986).

Conglomerates in the Rotokohu Coal Measures were derived from a distinctive Greenland Group source terrain, with a minor coarse-grained granite component (Section 2.3). The immediate source area for these lithologies is suggested by Nathan and others (1986) to be a juvenile Brunner-Victoria Range. The lower Longford Formation was largely derived from a Maitai Group source terrain, while the upper Longford Formation and lower Rappahannock Group were probably derived from a Caples/Pelorus terrain, both of which were situated to the east of the Waimea-Flaxmore and Alpine Fault Systems (Cutten 1979, Suggate 1979, Watters 1982, Nathan and others 1986).

The early Miocene stratigraphy of the Inangahua Valley (Chapter 2) indicates a rapid shallowing during the mid Altonian from mid to outer shelf (De Filippi Mudstone), to shallow marine (Ram Creek Member), to marginal and non-marine (Roto-

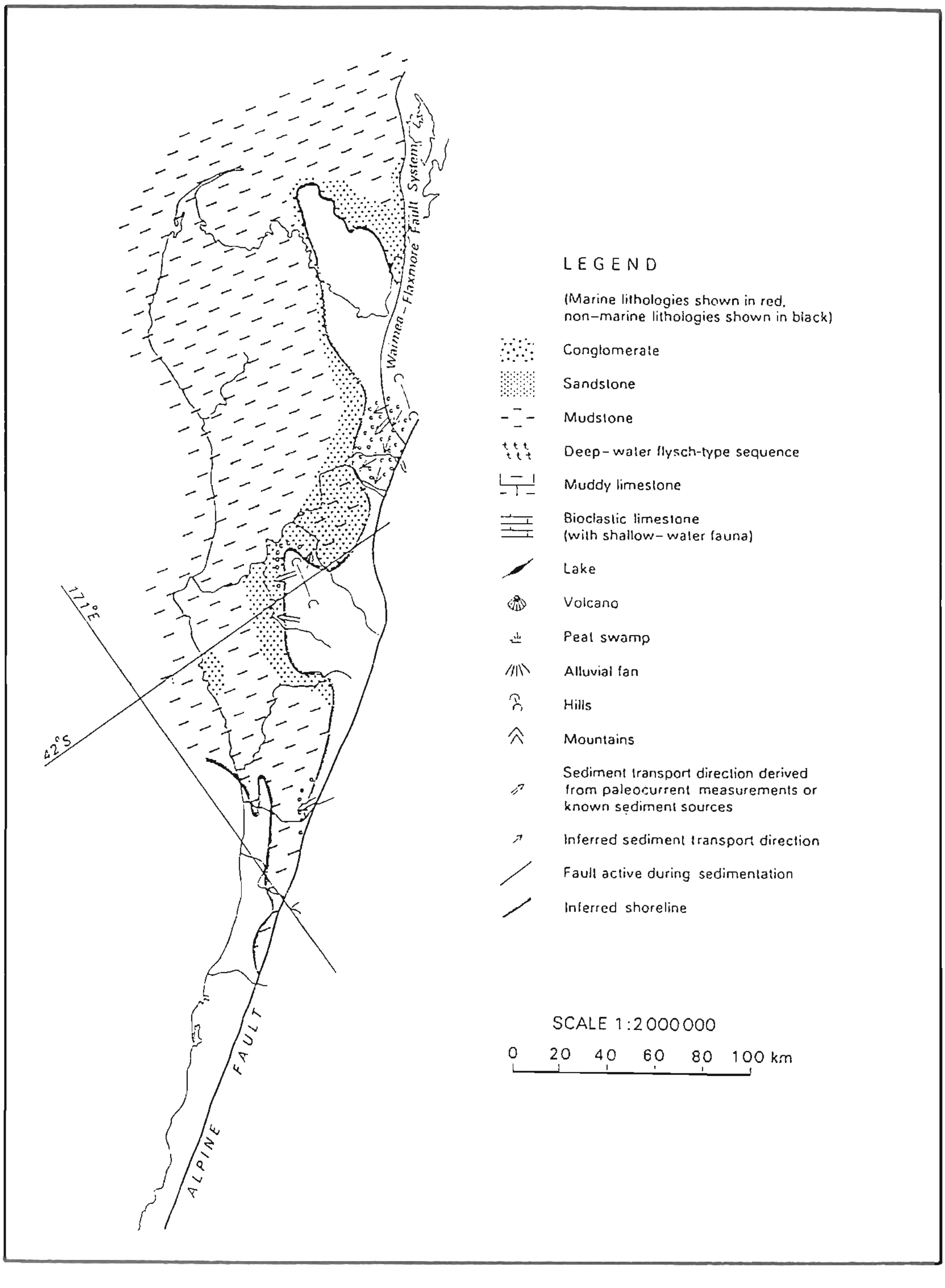


Figure 7.1: Regional paleogeographic interpretation for the Buller/ North Westland/ North-West Nelson region at late Altonian time (from Nathan and others, 1986). Red=marine sediments.

kohu Coal Measures) by late Altonian time. The distribution of sandstone within the upper Inangahua Formation (Section 2.1) reveals two major depocentres during the Altonian within the Inangahua Valley.

Relatively rapid subsidence and sedimentation north of Rotokohu is inferred to have resulted in a thicker upper Inangahua Formation and Rotokohu Coal Measures sequence than in the south (Chapter 2). Two depositional lobes are inferred within the rapidly subsiding northern Inangahua Valley, and the margins of the lobes are delineated in the upper Rough Creek area by the presence of:

a) a mudstone dominated facies of the Ram Creek Member (Section 2.2),
b) a relatively thick Thomson Member (Section 2.3), and
c) a thick mudstone dominated lithofacies sequence within the Camp Member at Gorgy Creek, which is interpreted as defining a region of sediment by-pass (Section 3.3).

Slower rates of sedimentation and subsidence south of Rotokohu resulted in a thinner Ram Creek Member (upper Inangahua Formation), and a finer grained coal measure sequence than in the north. The lower Giles Creek is considered to be the depocentre for early to late Miocene sedimentation in the southern Inangahua Valley, on the basis of a relatively thick Ram Creek Member which conformably overlies De Filippi Mudstone (Figure 2.5). The "basin" margins at Fletcher and upper Giles Creeks are characterised by a thin Ram Creek Member, and a disconformable Ram Creek/De Filippi Mudstone contact.

Palynological and paleobotanical studies indicate that a humid, sub-tropical or tropical climate existed in the Inangahua and Murchison valleys from late Altonian to Waiauan time (Mildenhall 1976, Holden 1982a and b). Microlithotype analyses of Rotokohu coal are dominated by the microlithotypes vitrite and clarite, suggesting a dominance of "woody" vegetation, a feature commonly considered by overseas researchers to be typical of seams deposited in tectonically unstable areas (Willimans V. and Ross C. 1979, Marchioni 1980). The reactives-rich inerts-poor maceral-group composition of Rotokohu coal suggests wet swamp conditions persisted at all times, and is consistent with both the humid sub-tropical to tropical paleoenvironment and rapid subsidence.

Clastic sediments and coal seams of the northern and southern Inangahua Valley are treated separately in the following discussion, in view of the major differences noted previously in the styles of sedimentation and probable rates of subsidence. The two paleoenvironmental models proposed were laterally equivalent, and the transitional area between the two environments is considered to have been in the Hunt/McMurray Creek region (Figure 7.2). This transitional region was a prominent tectostratigraphic feature within the Inangahua Valley from the early Miocene to the Pliocene, and is oblique to the dominant structural and sedimentation trends proposed by previous workers (e.g. Nathan and others 1986) for the Buller/North Westland region as a whole.

7.1.2 Northern Inangahua Valley

i) Paleoenvironmental Setting of the Thomson and Camp Members

Figure 7.3 shows the hypothetical paleogeographic reconstruction proposed for the Camp and Thomson Members at latest Altonian time. The Thomson Member is interpreted as a fluvial-dominated "lower delta plain" environment (Section 3.3). The interdigitation of brackish to marginal marine bioturbated sandstones (lithofacies Bs, Bz and Mft) with thin "marsh" sediments (lithofacies Fm and Cl) is characteristic of this member. The identification of a transitional zone such as the Thomson Member is the most significant feature for recognition of fan-delta deposits in the rock record (Westcott et al. 1980).

The distribution of the Thomson Member is directly related to the thickness of the underlying Inangahua Formation, and thinning of the Ram Creek Member south of Inangahua Landing defines the southern extent of the Thomson Member (Figure 2.5). Rapid sedimentation and subsidence north of Inangahua Landing is inferred to have resulted in a thick upper Inangahua Formation, and an interdigitation of marginal and non-marine environments to produce the Thomson Member.

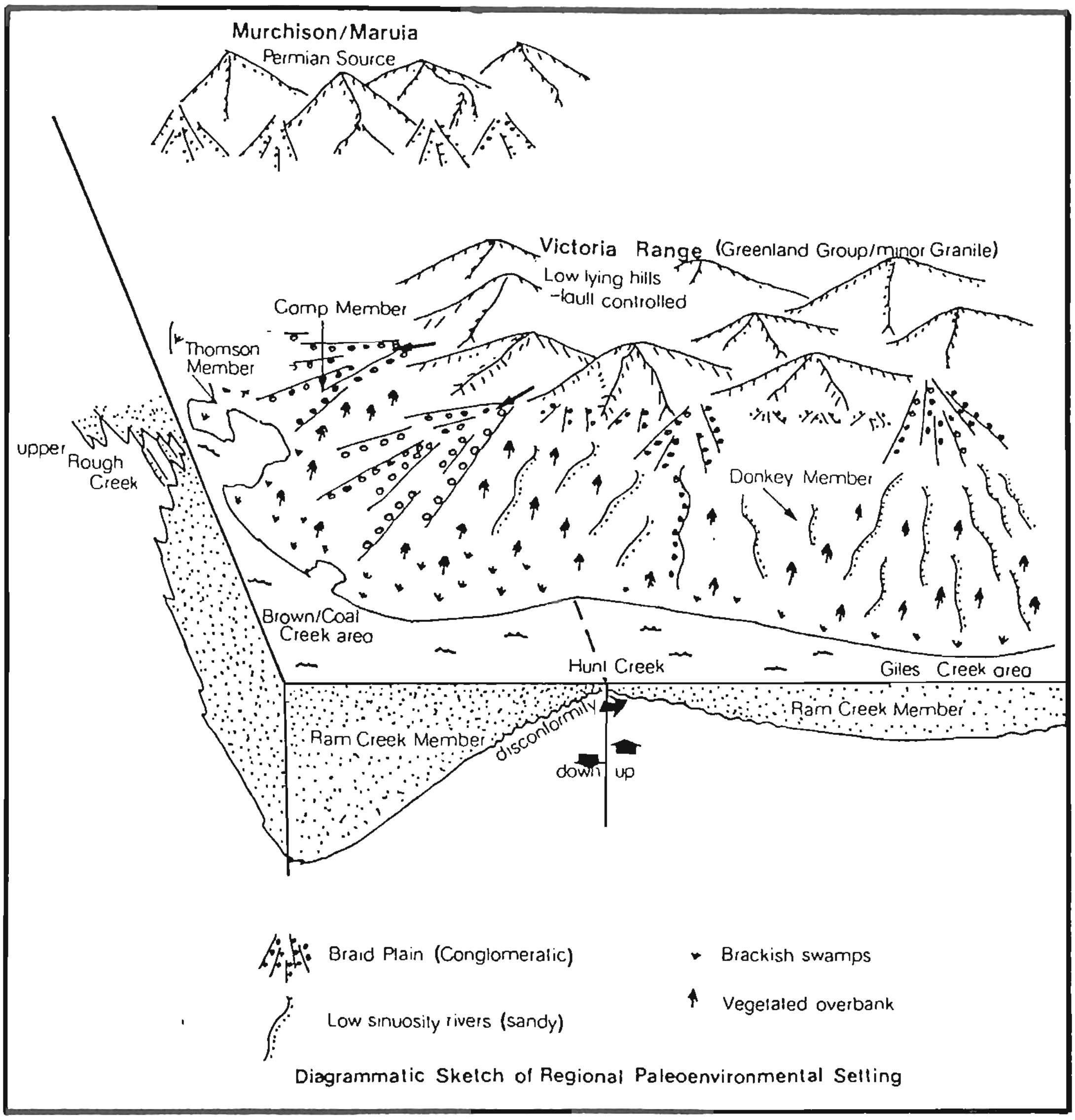


Figure 7.2: Diagrammatic sketch of the regional paleoenvironmental setting of the Rotokohu Coal Measures at late Altonian time.

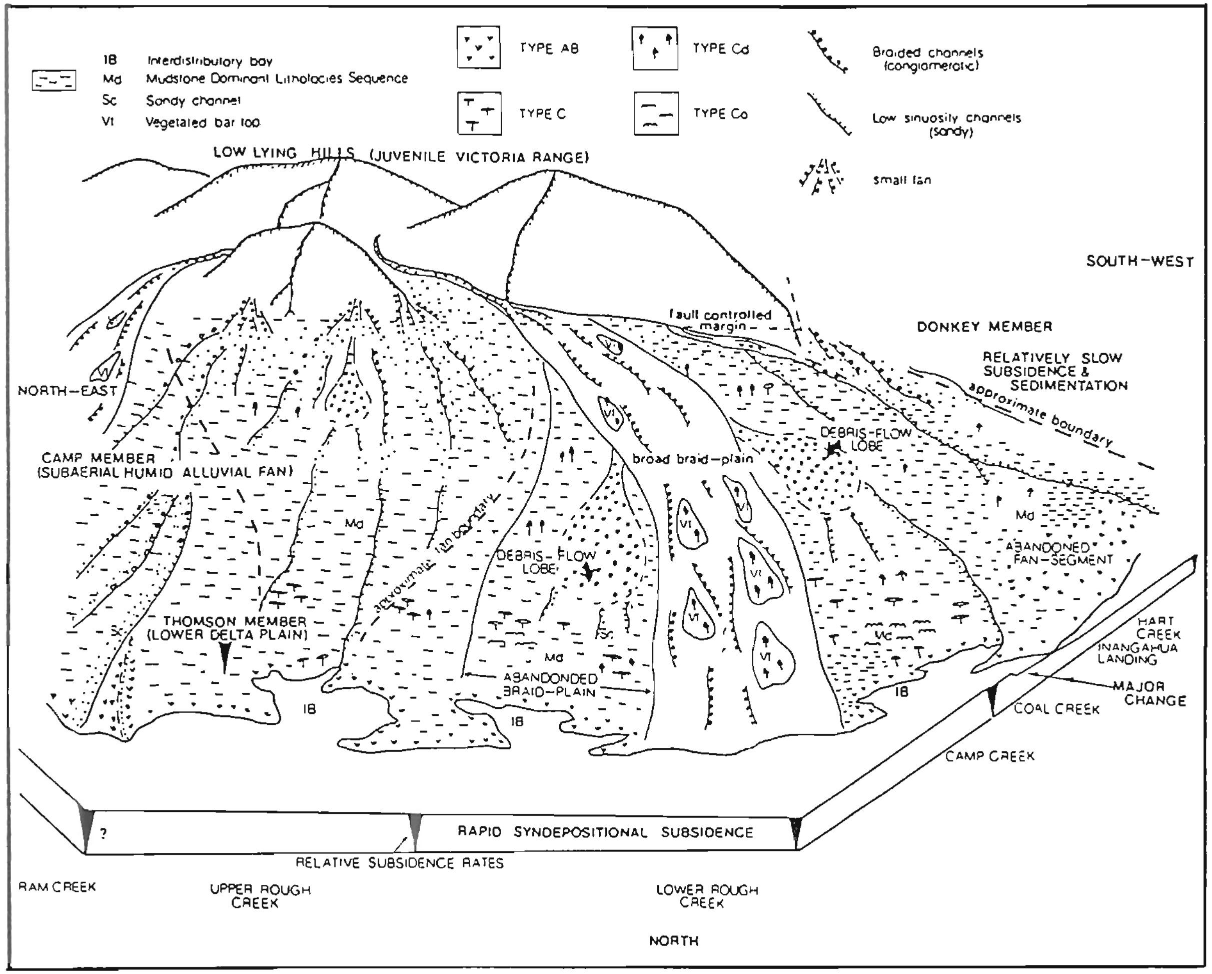


Figure 7.3: Paleoenvironmental reconstruction for the Camp and Thomson Members at late Altonian time. Possible relative subsidence rates are shown increasing to the north-east, with a major change near Inangahua Landing. Peat swamps are inferred to have primarily occurred as small pods on the subaerial humid alluvial fan (Camp Member), and as coastal marshes in the lower delta plain (Thomson Member).

The presence of relatively perhydrous vitrinites in the north-east (i.e. the upper Rough/Ram Creek area) relative to the west (i.e. the Coal/Camp Creek area), suggests a greater marine influence and/or poorer swamp drainage, both of which would be consistent with greater syndepositional subsidence in the north-eastern Inangahua Valley relative to the west.

Local thickening of the Thomson Member in the upper Rough Creek area is inferred to result from an autocyclic transgressive phase, probably produced by channel switching on two major coalescing alluvial fan systems (Section 3.3). The relocation of major distributaries is inferred to have resulted in the local development of marine influenced inter-distributary bay sequence (Section 3.3), within a stratigraphically higher position than elsewhere in the northern Inangahua Valley (Figure 2.5). Similar mechanisms of autocyclic transgressive phases producing and interbedding of marine influenced lower delta plain and delta-front sediments within upper delta plain sequences have been proposed in the literature (eg. Ryer 1981).

The Camp Member is interpreted as a subaerial, humid alluvial fan. Two major components are recognised in this member (Section 3.3):

a) a broad braid-plain environment (conglomerate-dominated lithofacies),
b) a predominantly fine grained, vegetated floodplain region (mudstone-dominated lithofacies).

The restricted distribution of conglomeratic channel (predominantly longitudinal bar) bed forms within the Camp Member is inferred to result from rapid syndepositional subsidence, and a probable point source for the major fluvial systems. High sedimentation rates are inferred to have resulted in frequent channel switching on the broad alluvial braid-plain, while rapid syndepositional subsidence is inferred to have allowed vegetated bars to form within the braid-plain environment (Section 3.3).

Thick mudstone deposits preserved within the Camp Member are interpreted as further evidence for rapid syndepositional subsidence, because fine grained sediments are usually not preserved in braided river environments (Miall 1977), except in instances of channel localisation (as outlined above), and/or through mechanisms of sediment by-pass (eg. Diessel 1984, Section 3.3). "Levee breaching" or escape of minor channels during periodic high flow stages, is the probable mechanism for the development of conglomeratic crevasse-splay horizons within the thick mudstone-dominated floodplain sequences.

Continued progradation of the humid alluvial fan sequences during the Southland Series resulted in a coarsening of the channel bedload, and an increased proportion of conglomerate in the Coal Creek area, as one of the braid-plains continued to be restricted in this region. A second major braid-plain is inferred from the distribution of sandstone in the underlying Ram Creek Member (Figure 2.5), to have existed further east of the Coal/Brown Creek area, but has subsequently been faulted-out by mid Pleistocene to recent fault movement on the Lyell Fault.

ii) Models of Peat Accumulation

Lower delta plain environments associated with large delta systems are well documented within the literature (Elliott 1978, Horne et al. 1978, Ryer 1984), and are characterised by a number of subenvironments with a variable marine influence (Figure 7.4). Coal seams within the lower delta plain environment of the Rotokohu fan-delta sequence (i.e. the Thomson Member) are predominantly composed of poorly drained, marine influenced, hypautochthonous to in part allochthonous Type AB coal. Variability in vitrinite reflectance, volatile matter yields, calorific value, and ash content and mineralogy, suggests that the type classification for Type AB coal is rather broad, and probably primarily reflects the marine influence.

Type AB coal within the Thomson Member always overlies bioturbated sandstones (interpreted in Section 3.3 as marine influenced interdistributary bays), or abandoned channel

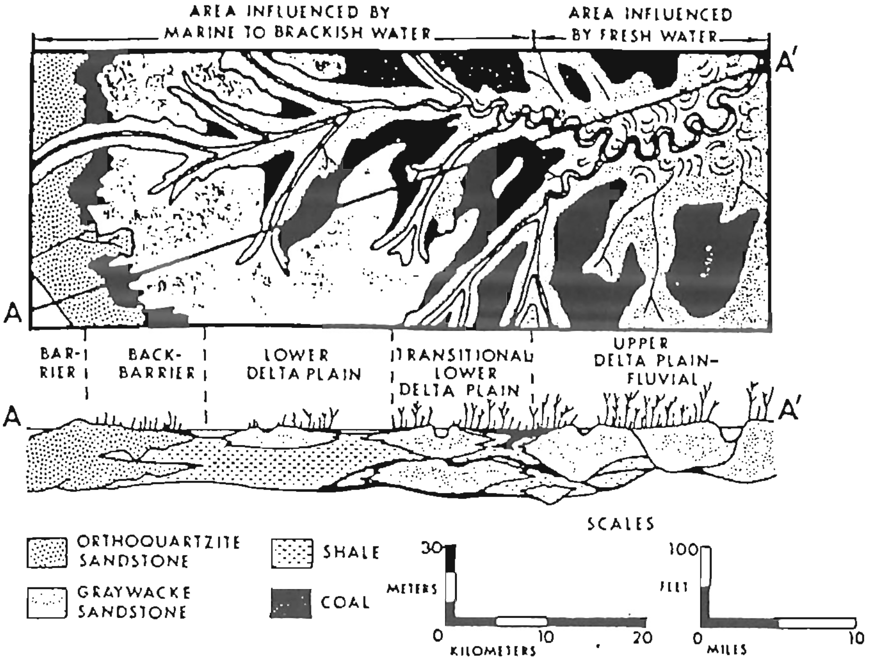


Fig. 7·4A Depositional model for peat-forming (coal) environments in coastal regions. Upper part of figure is plan view showing sites of peat formation in modern environments; lower part is cross section (AA') showing, in relative terms, thickness and extent of coal beds and their relations to sandstones and shales in different environments (modified from Ferm, 1976).

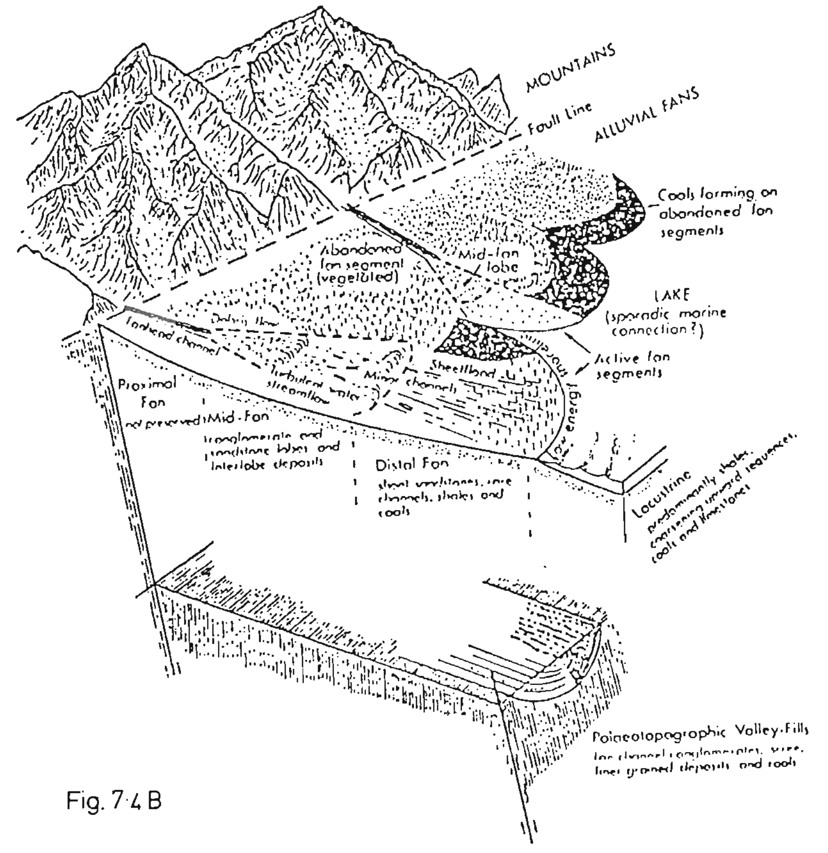


Fig. 7·4 B

Figure 7.4: A) Depositional model for peat-forming environments in coastal regions (from Horne et al. 1978)
B) Depositional model for the Stephanian A and B sediments of Spain (from Heward 1978)
The model for the Camp/Thomson Members (Figure 7.3) is essentially a combination of these two models, representing a parallic fan-delta setting.

sequences, and is inferred to represent small coastal swamps of limited lateral extent. The abundance of thin Type AB coal seams within the Thomson Member is inferred to result from frequent relocation of distributary channels in the lower delta plain, producing an interdigitation of marine and non-marine sediments, which resulted in a corresponding repetition of short-lived Type AB swamps. This cyclic repetition of marine and non-marine sediments is also inferred to be the cause of the high sulphur content of coals within the Thomson Member (Section 5.4).

Coal seams within the Camp Member north of Inangahua Landing are composed exclusively of coal types C, Cd and Co. Thin coal seams are the norm (<1.5m), indicating the generally unfavourable nature of an actively prograding humid alluvial fan to coal seam development (Heward 1978).

Type C coal is inferred to represent poorly drained, low energy overbank settings, where small, localised leaf accumulations were able to form (Section 6.6). Thin (<1m) seams of Type C coal frequently occur in overbank mudstone deposits (lithofacies sequence M) throughout the northern Inangahua Valley.

Type Co coal also crops out within overbank sediments of the Camp Member (lithofacies sequence M), commonly in slightly thicker seams than Type C coal (up to 1.5m), and is inferred to represent well drained swamps, relative to Type C coals (Section 6.6). These swamps appear to have developed only locally, and are represented by seams in the lower Camp Member at Camp Creek, and a single seam in the thick Thomson Member at Rough Creek.

The lower Camp Member at Camp/Coal Creek is probably the Rotokohu equivalent of the "transitional delta plain" (Horne et al. 1978); i.e. the transition between lower delta plain sediments of the Thomson Member, and the alluvial fan channel sediments of the upper Camp Member. The relatively well drained, slightly thicker Type Co swamps were able to develop locally in this environment. Type Co peat swamps were probably of greater lateral extent than the localised Type C leaf accumulations, and the lenticular "coastal swamps" (Type AB coal) of the Thomson Member, however extremely poor exposure inhibits an accurate assessment of seam geometry.

Type Cd coals are interpreted as representing leaf accumulations within a higher energy environment relative to Type C coal (Section 6.6). Type Cd coal occurs within both lithofacies sequence M (fine grained overbank deposits), and lithofacies sequence C (broad braid-plain environment).

In lithofacies sequence M, Type Cd coal occurs as very thin seams (generally <0.5m) interbedded with fine mudstone sediments, and is inferred to be transitional to the low energy Type C peat accumulations. In lithofacies sequence C, Type Cd coal occurs in bar top sequences, where vertical accretion on abandoned bar surfaces is inferred to have favoured the development of thin peats. Vegetation of bar tops appear to have been relatively common in the northern Inangahua Valley, and is inferred to have formed in response to better drainage afforded by the abandoned bar surface, as opposed to the generally poorly drained floodplain.

The Camp Member only includes Type AB coal south of Inangahua Landing, in the Hart Creek area. The "lower delta plain" Thomson Member is not present in this area, and the Camp Member conformably overlies the Ram Creek Member. Two samples of Type AB Coal were identified from the thick lithofacies sequence M present at Hart Creek (samples 11860 and 11863).

The development of Type AB coal is inferred to represent a greater marine influence in the lower Camp Member in this area, relative to north of Inangahua Landing. Thickness variations in the underlying Ram Creek Member (Figure 2.5) suggest that the Hart Creek area may represent a region of less rapid syndepositional subsidence and/or sedimentation, and this may have favoured the development of a thick (>7m), possibly laterally continuous (Suggate and Wellman 1949) peat deposit.

7.1.3 Southern Inangahua Valley

i) Paloenvironmental Setting of The Donkey Member

The Donkey Member is the only member recognised within the Rotokohu Coal Measures south of McMurray Creek, and is the lateral equivalent of the Thomson and Camp Members in the north. Three lithostratigraphic components are recognised within the Donkey Member (Section 3.3):

a) a thick (approximately 30m), laterally continuous, poorly drained swamp deposit gradationally overlying the Ram Creek Member,
b) channel/levee sequences,
c) overbank sequences, containing both well drained and poorly drained swamps, interbedded with the channel/levee sequences.

The proposed paleoenvironmental reconstruction for the Donkey Member is shown in Figure 7.5. The thick, poorly drained swamp horizon at the base of the member is characterised by thick coal (>3m, locally up to 30m), with numerous intercalations of ripple laminated sandstone (lithofacies Sr), and massive mudstone (lithofacies Fm). The presence of marine dinoflagellates within this horizon (Mildenhall pers. comm.), the gradational nature of the contact with the marine Inangahua Formation, and the dominance of marine influenced Type AB coal, are consistent with a coastal depositional environment.

The vertical sequence defining the transition from the Inangahua Formation to the Donkey Member has broad similarities to regressive coastal sequences defined in the literature (Reineck and Singh 1980, Ryer 1981). The general lack of structures within the shallow marine Ram Creek Member (Appendix 12) may suggest a relatively low energy coastal environment. A laterally extensive, poorly drained coastal marsh deposit (the base of the Donkey Member) is inferred to have formed at the front of an alluvial plain which prograded from the juvenile Victoria Range south of Rotokohu.

A similar regressive marine/fluviodeltaic cycle was proposed by Newman J. (1984) for Miocene coal measures in the Waitewhena Coalfield (Taranaki), and is probably a useful analogue for the Rotokohu Coal Measures in the southern Inanga-

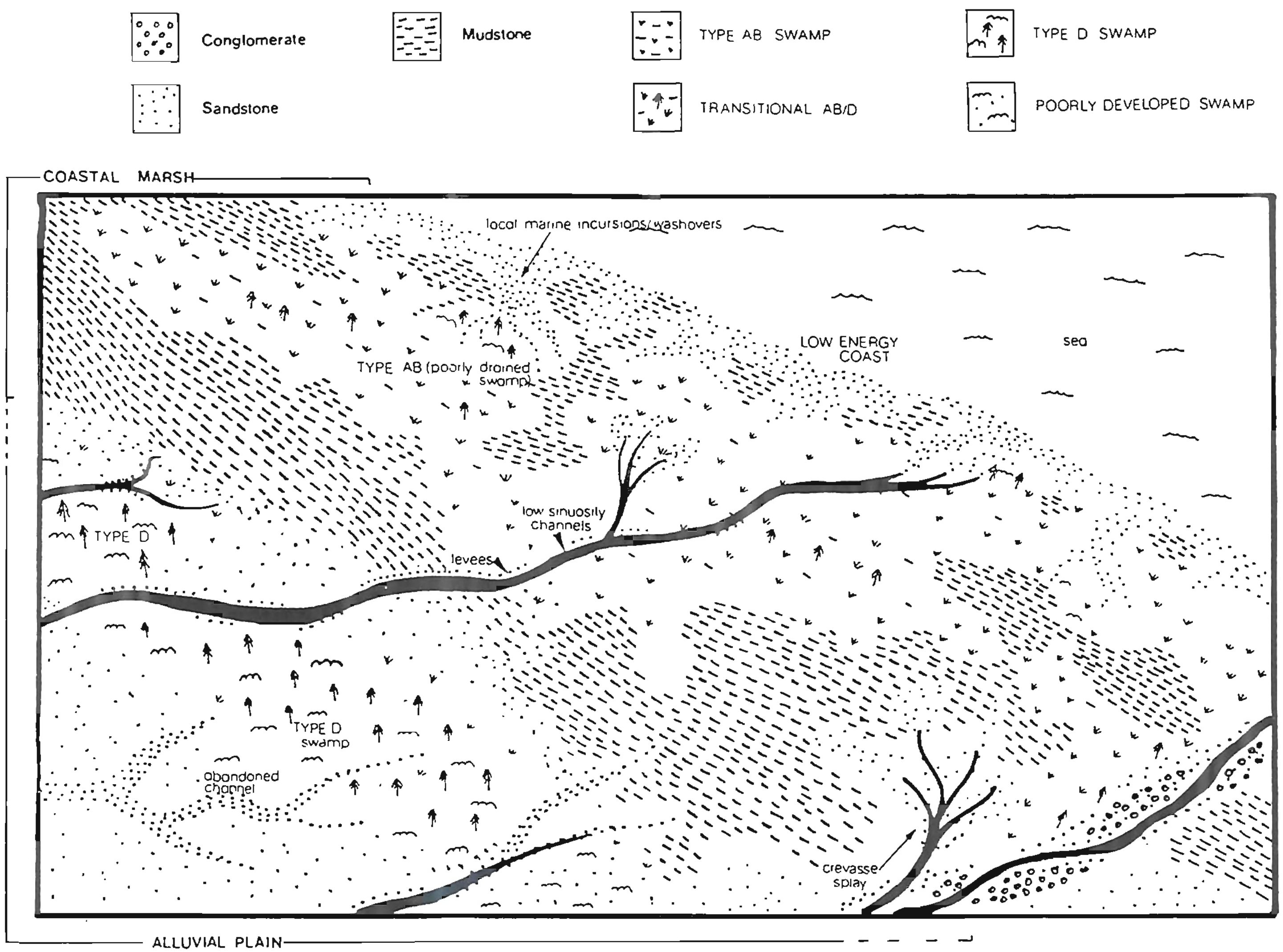


Figure 7.5: Paleoenvironmental reconstruction for the Donkey Member showing the two main lithostratigraphic components recognised:
a) a coastal marsh, and
b) an alluvial plain.

hua Valley.

The coastal marsh deposits of the Donkey Member are overlain by a thick alluvial plain sequence comprising channel/levee deposits and fine grained overbank sediments. The channel/levee sediments are volumetrically dominant in this alluvial plain sequence in most outcrops, with thick overbank sequences only observed in the lower Giles Creek area in DH 118 and at Giles Creek Mine.

Channel morphology on the alluvial plain was interpreted previously (Section 3.3) from limited vertical sequences to be characterised by low sinuosity, predominantly sandy channels, with relatively well developed levees. Frequent levee breaching is indicated by the presence of numerous crevasse-splay sandstones, and abandoned crevasse-splay channel fill deposits identified at Giles Creek Mine and in DH 118 (Section 3.3).

Thick overbank sequences appear to have only developed locally within the alluvial plain environment. The "basin margin" at Fletcher Creek is characterised by an absence of overbank deposits, and may reflect relatively slower syndepositional subsidence in this area. More rapid syndepositional subsidence during the early Miocene in the Giles Creek area is interpreted as resulting in a relatively thick Ram Creek Member (Figure 2.5), and an abundance of fine grained overbank sediments within the Donkey Member. Similar relationships between rapid syndepositional subsidence and the preservation of thick fine grained overbank sediments within low sinuosity to braided river environments are proposed by McLean and Jerzykiewicz 1978, and Friend 1978.

ii) Models of Peat Accumulation

The laterally continuous, poorly drained coastal marsh deposit is characterised by thick (>3metres), marine influenced Type AB coal. The high water table in this coastal swamp environment favoured the development of frequent clastic partings and variable ash contents. Consequently the basal seam of the Donkey Member is characterised by numerous intercalations of mudstone and sandstone, which were inferred previously (Section 3.3) to represent various crevasse-splay deposits and small intra-swamp paleodrainage channels.

Large intra-swamp paleodrainage channels, although not observed during mapping, probably existed within this poorly drained coastal swamp, and are the likely source of the frequent crevasse-splay deposits. Such intra-swamp paleodrainage channels can be expected to form major seam washouts. Small marine incursions/washover fans may also have developed to introduce marine dinoflagellates into the swamp, although direct evidence of any such incursions was not observed during mapping.

The high water table and marine influenced depositional environment also induced the development of perhydrous vitrinites, with elevated volatile matter yields and calorific values, and suppressed reflectance. Variations in ash content within the basal seam (DH 118 proximate analyses, and Giles Creek Mine samples; Appendix 8), and slight variations in vitrinite reflectance (Ro=0.30-0.34%) may reflect variations in swamp drainage, and/or a variable marine influence. Either mechanism is probable given the coastal depositional environment proposed for the basal seam. More proximate, maceral, ash constituent, and reflectance analyses are required to accurately assess controls on the variability of reflectance in Type AB coal.

The frequent occurrence of siliceous partings associated with the roof and floor of seams and crevasse-splay sandstones, coupled with the general absence of feldspar in coal ash analyses, suggests an early "diagenetic" change from marine influenced (i.e. alkaline) swamps to acidic conditions shortly after burial within Type AB coal (Section 5.3).

Overbank swamp deposits within the alluvial plain environment only crop out at the Giles Creek Mine, where a second major seam is observed to abruptly overlie channel/levee sediments (Figure 3.26). This coal is classified as Type D, representing a well drained (possible raised), hypautochthonous to autochthonous, peat swamp. Channel abandonment was proposed as the mechanism for allowing the development of this thick well drained swamp sequence (Section 3.3), and resulted in a distinctive coal type with very low ash content, higher reflectance and lower volatile matter yield than perhydrous poorly drained Type AB coals. The abandoned channel sequence provides a relatively well drained base for peat accumulation, which is maintained during the life of the swamp by differential compaction of the surrounding fine grained overbank sediments and less well drained peat swamps, relative to the channel sandstones (R. Flores pers. comm.)

Overbank sediments cored in DH 118 comprise both poorly drained (lithofacies Fm, Fl and dirty coal) and well drained (low ash coal) deposits. The variable coal quality (indicated by proximate analyses) in most seams suggests fluctuating water levels during peat swamp history. Further analytical work (i.e. vitrinite reflectance and maceral analyses) will enable a more refined depositional model to be proposed for these deposits.

7.2 IMPLICATIONS OF DEPOSITIONAL ENVIRONMENT TO COAL SEAM DISTRIBUTION AND CHARACTER

7.2.1 Northern Inangahua Valley

The presence of numerous thin (<1.5m) coal seams within the Rotokohu Coal Measures north of Inangahua Landing has been noted since the turn of the century (Henderson 1917). The depositional model proposed here interprets the coal measure sequence in this area as a prograding fan-delta sequence characterised by a broad braid-plain environment, and both high sedimentation rates and rapid syndepositional subsidence.

Rapid syndepositional subsidence and channel switching resulted in an interdigitation of marine and non-marine environments at the base of the coal measure sequence (i.e. Thomson Member). This "lower delta plain" environment is considered unlikely to have generated economic coal reserves, and is characterised by thin (<1.5metre), laterally discontinuous, marine influenced coals (Type AB), with characteristically high sulphur contents.

Thin, laterally discontinuous, low sulphur coal "seams" which developed locally on the rapidly subsiding humid alluvial fan (i.e. the Camp Member), are also considered uneconomic. The "twenty feet of coal" reported by Wellman (1950) in the Camp Creek area refers to a horizontal Type Co coal seam outcropping within the lower Camp Member (i.e. the transitional region between lower delta plain and alluvial fan sediments), in the core of the Inangahua Syncline. The estimated true thickness of this seam is approximately 1.5m, and it is not considered a significant resource.

In summary, high rates of sedimentation and rapid syndepositional subsidence north of Inangahua Landing have resulted in numerous, thin, reactives-rich coal seams, of limited lateral extent, with high sulphur coals occurring at the base of the coal measure sequence. Progradation of a humid alluvial fan environment resulted in an increase in conglomeratic sedimentation and a general absence of coal seams towards the top of the coal measures. The findings of this study confirm those of Nathan (1978a), that the Rotokohu Coal Measures do not contain economic reserves of coal north of Inangahua Landing.

A period of "partial lobe abandonment" during the late Altonian at Hart Creek, coupled with possibly slightly slower syndepositional subsidence rates (relative to north of Inangahua Landing), is considered as a possible model to explain the occurrence of thick, laterally persistent (7metres) coal. Abandonment facies in deltaic and fan-delta environments commonly consist of laterally persistent fine grained marker horizons (Elliott 1978, Heward 1978). The correlation proposed by Suggate and Wellman (1949) for vertically dipping 7m coal outcrops associated with a thick mudstone dominated lithofacies sequence in the Hart Creek area is tentatively supported by the hypothesis of partial lobe abandonment, and further exploration is recommended in this area to test the lateral persistence of these outcrops.

7.2.2 Southern Inangahua Valley

The Donkey Member contains a potentially significant reserve of opencastable, low sulphur coal. The depositional model proposed identifies two environments of potential peat swamp development,

a) a poorly drained coastal marsh,
b) locally developed overbank swamps,

The laterally persistent coastal marsh environment contains a single, thick (>3metres) low sulphur coal seam at all known outcrops. Frequent intercalations of crevasse-splay deposits result in an apparently dissimilar pattern of coal and interseam sediments, which led previous geologists to consider that exposures of this seam represented lenticular pods of thick coal. The model proposed in this thesis attributes these outcrops to a single, thick, laterally persistent low sulphur seam, extending along strike for a minimum of 6.5 km from Fletcher Creek in the north, to the West Branch of Giles Creek in the south.

Numerous crevasse-splay and intra-swamp paleodrainage channels result in variable coal quality, and will be a major influence on any future mining or prospecting activities. Major washouts are expected to occur within this seam, representing the major fluvial channels from which the crevasse-splay sandstones originated.

The second peat swamp environment identified in the proposed depositional model are overbank settings between the major fluvial axes. Such environments appear to have only been preserved within the rapidly subsiding central "basin" and are absent from the "basin" margin at Fletcher Creek.

Overbank peat swamp deposits within the alluvial plain environment are considered unlikely to have the same lateral continuity as the poorly drained coastal marsh environment. The inferred low sinuosity of the rivers, and evidence for major episodes of channel abandonment, indicate that peat in this environment probably accumulated as small protected swamps, which locally attained considerable thickness. Three such seams were encountered within the Donkey Member in DH

Overseas research suggests that the development of seam splits in similar low sinuosity river environments leads to rapid seam disintegration towards the sediment source (i.e. the adjacent fluvial channel), producing distinctly lenticular "pods" of relatively thick peat (R. Flores pers. comm.).

The regional Wanganui unconformity is a further control on the potential coal resource in the Donkey Member. The unconformity is distinctly angular on the "basin" margins at Fletcher and upper Giles Creeks, and in the ridge between lower Giles Creek and Stony River, truncating the entire coal measure sequence (except 2m in the lower Giles Creek area). The unconformity places a major limit on the potential coal reserve within the Donkey Member, defining two blocks where the member is preserved:

1) Stony/Fletcher Creek block, and
2) mid Giles Creek block.

The low sulphur content of coals from the Donkey Member is attributed to the regressive nature of the member. Syndepositional enrichment of the brackish influenced basal Donkey Member seam does not appear to have contributed significantly to the sulphur content of this Type AB coal. The high sulphur content of Type AB coals in the Thomson Member is interpreted as resulting from autocyclic transgressive phases (Section 5.4). The absence of such transgressive phases in the Donkey Member suggests that sulphur enrichment within Rotokohu coals is directly attributable to secondary enrichment via percolating marine solutions, either from small autocyclic transgressive phases allowing immediate post-depositonal enrichment of the peat with sulphur (as is probably the case in the Thomson Member), or late stage enrichment during the major regional transgression (as occurs in the occasional high sulphur coal from the upper Camp Member and in the basal Donkey Member near the Giles Creek Mine).

7.3 GEOLOGICAL HISTORY

7.3.1 Pareora

Marine Pareora sediments within the Inangahua Valley indicate rapid shallowing which culminated in the late Altonian with deposition of the locally derived, essentially non-marine Rotokohu Coal Measures. Thickness variations within the underlying marine upper Inangahua Formation indicate two depocentres of early Miocene sedimentation, one north of Inangahua Landing, and a second in the south in the lower Giles Creek region.

7.3.2 Southland

Coal measure sedimentation continued throughout the Southland Series within the Inangahua Valley. Rapid, probably fault controlled subsidence and sedimentation in the northern Inangahua Valley resulted in a thick conglomeratic, fan-delta sequence, with numerous thin inerts-poor, reactives-rich coal seams (Thomson and Camp Members). Less rapid subsidence and sedimentation in the south resulted in a relatively thin, predominantly sandy coal measure sequence, with locally thick, inerts-poor, vitrinite-rich coal seams (Donkey Member).

Dextral strike-slip on the Alpine Fault may be the mechanism which resulted in a local extensional regime ("pull-apart basins") in the Inangahua/Murchison area, with a structural trend oblique to the regional north-north-east trend which dominates all previous, and most subsequent sedimentation and structural elements in the Buller/North Westland area.

Evidence from outside of the field area suggests that coal measure sedimentation was localised, with marine sediments of similar age occurring further south at Slaty Creek (a small tributary of Big River, approximately 30 km south-west of Giles Creek; Suggate, 1957), and Greymouth (Stillwater Mudstone, Nathan 1978b). No Southland aged sediments are preserved north of Welshman Pakihi in the northern Inangahua Valley.

7.3.3 Taranakian

No Taranakian sediments are preserved within the Inangahua Valley. Coal measure sedimentation may have ceased during the late Waiauan to early Tongaporutuan, possibly corresponding to renewed transgression as evidenced by:

a) marine sediments of this age in coastal sections (the O'Keefe Formation, Nathan 1978a & b, and Nathan and others 1986),
b) the distinct reduction in conglomerate clast size noted in the upper Camp Member (probably late Southland [Waiauan ?]) at Coal Creek, and
c) the presence of shallow marine sediments within the overlying Giles Formation.

Deformation within the period from the Waiauan to Opoitian is indicated by local tilting and erosion of the Rotokohu Coal Measures and lower Tertiary sediments prior to deposition of the Giles Formation (Section 4).

7.3.4 Wanganui

Wanganui sediments within the field area are represented by the Giles Formation. The base of the Giles Formation is possibly Opoitian, although the bulk of the formation is Waipipian. In the northern Inangahua Valley the Giles Formation is wholly marine, representing the deposits of a large, sheltered, full salinity bay environment (Section 2). Bay sediments grade south into non-marine, predominantly granitic sediments near Reefton (Suggate 1957), indicating that a locally derived alluvial sequence existed in the southern Inangahua Valley at this time.

A proposed paleogeographic reconstruction for the early Waipipian is shown in Figure 7.6. Locally derived sedimentation, which characterises the Giles Formation, was abruptly terminated during the mid to late Waipipian by an influx of coarse, allochthonous detritus derived from east of the Alpine Fault System (Old Man Group). The Old Man Group represents the deposits of a broad alluvial plain which formed west of the rapidly rising Southern Alps (Nathan and others 1986).

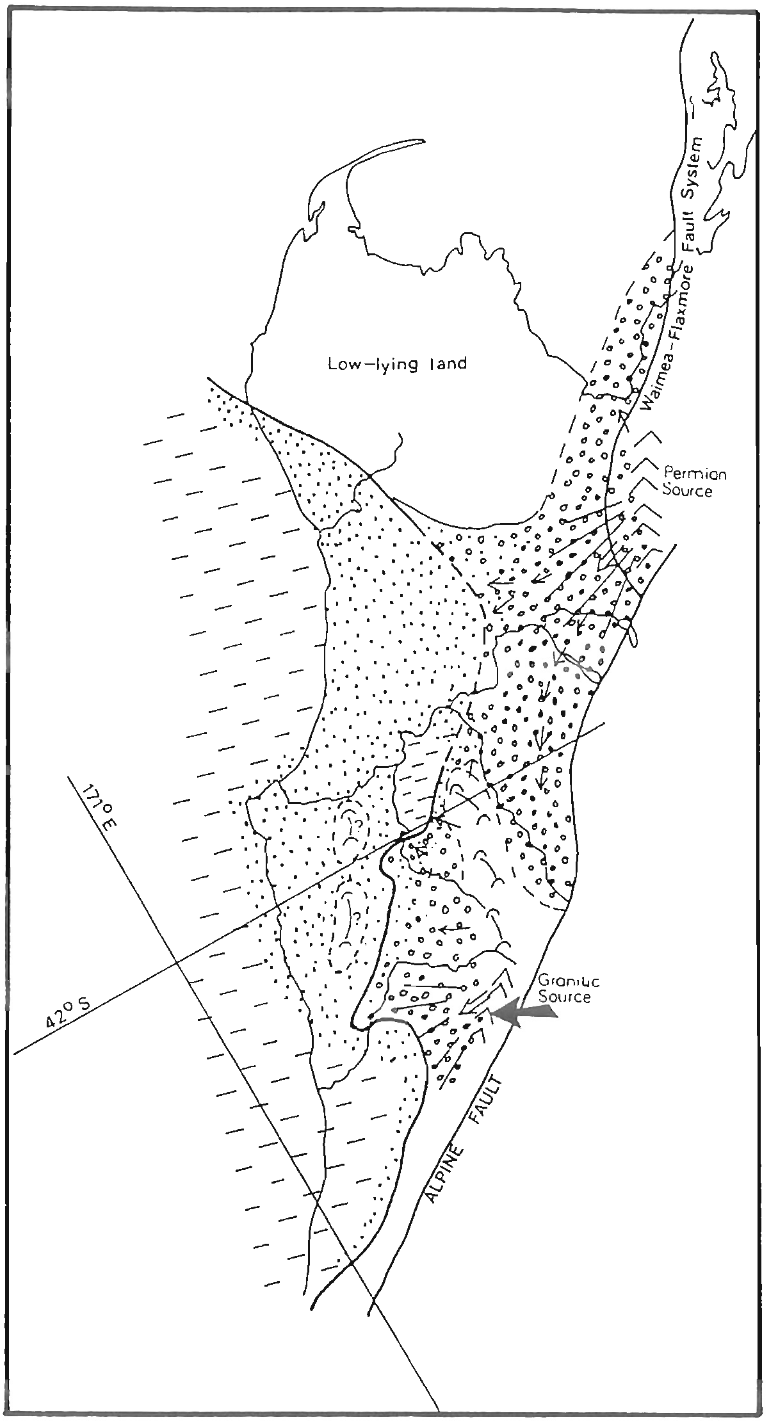


Figure 7.6: Possible paleographic reconstruction for the Inangahua Valley in the early Waipipian (modified after Nathan and others 1986). Red=marine.

7.3.5 Quaternary

Deposition of the Old Man Group continued into the lower Pleistocene within the Inangahua Valley. Widespread mid Pleistocene compressional tectonics within the Buller/North-Westland region resulted in the development of upfolded and upfaulted mountain ranges, with downfaulted Tertiary sediments predominantly folded into asymmetric, open synformal folds (Section 4). Aggradation and degradation during subsequent upper Pleistocene glaciations formed a series of distinctive outwash surfaces within the valley bottom of the Grey-Inangahua Depression, with continued deformation producing a series of post glacial fault traces on these surfaces.

7.4 RECOMMENDATIONS FOR FUTURE WORK

Work undertaken during this investigation has highlighted the need for more study within various fields of geology where the data currently available was found to either require more refinement, or to benefit from more research. In view of these problems, the following recommendations are made:

1) Remapping of the Miocene to Pliocene stratigraphy of the Grey-Inangahua Depression, in view of the identification of a major regional Wanganui unconformity during the current investigation.

Group nomenclature based on hand specimen identification of allochthonous clasts adopted in this thesis is probably the most practical method of mapping the complex interdigitation of marine and non-marine sediments within the Grey-Inangahua Depression. The current Group nomenclature is, to a degree, based on subjective genetic criteria (i.e. the identification of marine or non-marine depositional environments), and should form the basis of any subsequent formation subdivision.

One criticism of the Group nomenclature used in this thesis and by Nathan (1978a) in the northern Inangahua Valley, is that all late Miocene to Pliocene sediments from the Murchison/Maruia basin are derived from east of the Alpine Fault, and according to this classification are therefore Old Man Group sediments.

2) Vitrinite reflectance, maceral, and fluorescence studies are recommended for coal samples from DH 118 to help clarify some of the relationships noted in previous sections between coal type and analytical properties (i.e. volatile matter/reflectance).

Clarification of in-seam variations in coal properties will enable the development of a more refined paleoenvironmental model for the Donkey Member, and will aid future prospecting and mine planning. Such information will also serve as a valuable data base for reactives-rich coals of similar age in the Taranaki region, and for low rank, vitrinite-rich coals in general.

3) Geochemical work is recommended on samples from DH 118 to evaluate the affects of outcrop weathering on the high temperate ash chemistry of the samples determined in this thesis.

4) Exploration is recommended in the Giles Creek, and Stony/Fletcher Creek areas to assess the potential coal resource within the Donkey Member.

In view of the multi-seam nature of the Donkey Member at Giles Creek, it is recommended that future prospecting and mining licenses should be granted in such a way that the entire member is evaluated, to avoid "high-grading" of the potential reserve to the most readily found (i.e. the basal seam), and the most easily extractable coal.

Prospecting is also recommended in the Hart Creek area to determine the lateral persistence of the 7m outcrops noted by Suggate and Wellman (1949) in this area.

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APPENDIX 1

Sample Summary

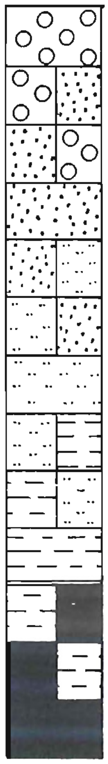
U.C.No.	Grid Ref. NZMS 260	Analyses Performed					
		Maceral	Micro-lithotype	Reflectance	Proximate	XRD	XRF
11804	L30 108075	x			x		x
11805	L30 108075				x		x
11806	L30 108075						x
11807	L30 108075	x					x
11808	L30 108075	x			x		x
11809	L30 108075	x			x		x
11810	L30 159181			x	x		x
11811	L30 108077	x				x	x
11812	L30 108077	x			x	x	x
11813	L30 108077	x					x
11814	L30 108077	x			x		x
11815	L30 108077	x				x	x
11816	K30 097058	x	x	x			
11817	L30 218191	x				x	x
11818	L30 225192	x		x			
11819	L29 208204	x					
11820	L29 231237	x		x			
11821	L29 250203	x		x			
11822	L30 108075	x			x	x	x
11823	L29 210202	x		x	x		
11824	K30 092053	x				x	x
11825	K30 092053	x	x	x	x	x	x
11826	L29 213213	x	x	x	x		
11827	L29 240204	x			x		
11828	L29 265228	x					
11829	L29 264229	x	x	x	x		
11830	L29 225221	x					
11831	L29 284247	x		x			
11832	L29 212205	x	x	x	x		
11833	L29 250229	x		x			
11834	L29 286254	x					
11835	L29 205205	x		x			
11836	L29 261224	x		x			
11837	L29 261221	x		x		x	x
11838	K30 065053	x		x	x		
11939	L29 262220	x		x	x		
11840	L29 208204	x		x			
11841	L29 225221	x	x		x		
11842	L29 218206	x					
11943	L30 255199	x		x	x		

L.C.No.	Grid Ref. NZMS 260	Analyses Performed Maceral	Micro-lithotype	Reflectance	Proximate	XRD	XRF
11844	L29 208203	X					
11845	L29 213201	X				X	X
11846	L29 211203	X					
11847	L29 208204	X					
11848	L29 243298	X		X	X		
11849	L29 233221	X			X		
11850	L30 108075	X					
11851	No sample						
11852	L29 262221	X		X	X		
11853	K30 052063	X					
11854	L30 218191	X					
11855	L30 228193	X		X	X	X	X
11856	K30 091060	X		X		X	X
11857	L29 235207	X		X			
11858	L29 208204	X					
11859	K30 097058	X		X	X		
11860	L30 158173	X					X
11861	L30 158173	X			X	X	X
11862	L30 158173	X	X	X	X		
11863	L30 158173	X			X		X
11864	L30 115102	X		X		X	X
11865	L30 125124	X		X			
11866	L30 125124	X					
11867	L30 125124	X					
11868	L30 108077	X		X			
11869	L30 108075	X					
11870	L30 108075	X			X		
11871	L29 206204	X		X			
11872	L29 236257	X	X	X	X	X	X
11873	L29 233236	X			X		
11874	L29 260224	X					
11875	L30 218158			X			
11876	L30 232189			X			
11877	L30 238181			X			
11878	L30 238181			X			
11879	L29 213213	X		X	X		
11880	No sample						
11881	L29 208203					X	X
11882	L30 108077					X	X

APPENDIX 2

LEGEND TO STRATIGRAPHIC COLUMNS

ROCK TYPES



gravel
sandy gravel
gravelly sand
sand
silty sand
sandy silt
silt
clayey silt
silty clay
clay
coaly clay
clayey coal
coal

c carbonaceous

c very carbonaceous

BIOGENIC STRUCTURES

burrows
bored surface
churned, bioturbated
roots/rootlets
stems/branches
R resin globules
leaves (entire)
plant fragments

Macrofossils Present In The Winding Shelly Sandstone

Sample No. / Location	S31/f557 Coal Creek	S31/f574 Inangahua River East Bank	S31/f583 Inangahua River West Bank	S31/f520 Shag Creek	S31/f584 Hunt Creek	S31/f576 Giles Creek
BIVALVIA						
Glycymeris sp.					X	
?Limopsis sp.					X	
Ostrea (Tiostrea) puelchana lutania	X	X	X	X	X	
Anomia trigonopsis	X	X		X	X	
Patro undatus						X
Perna canaliculus	X	X		X	X	X
Aulacomya ater maoriana						X
Xenostrobus aff. hutttoni	X					
Modiolarca impacta				X		X
Limatula maoria					X	
Taras (Zemysina) aff. zelandica				X	X	X
Cyclomactra cf. ovata	X					
Tawera sp.						X
Austrovenus aff. stutchburyi	X					
Ruditapes n.sp.aff. largillierti	X	X	X		X	X
Dosina n.sp. (as at Waipipi)					X	
Bassina cf. yatei	X					
GASTROPODA						
Calliostoma sp.				X		
Crepidula radiata	X	X	X		X	X
Zegalerus cf. tumens	X					
Zeacumantus cf. tirangiensis		X				
Macricolpus aff. ongleyi					X	
Tanea zelandica		X				
SCLERACTINIA						
Platyhelia distans					X	
Oculina virgosa					X	

APPENDIX 3

APPENDIX FOUR

COAL SAMPLE PREPARATION

All coal samples used for maceral, microlithotype, vitrinite reflectance, and geochemical studies were obtained from stream outcrop or mine face exposures. Most samples consist of full seam channel samples, reflecting the abundance of thin seams (<1m) within the study area, while a few grab samples (i.e. selective samples taken from a restricted portion of the seam) were obtained from thicker seams.

On completion of field work, all samples collected were crushed to -4mm using a mechanical jaw crusher. Representative sub-samples were then obtained for proximate and maceral analyses using a sediment sample splitter.

Preparation of Particulate Mounts

a) A small sub-sample of approximately 100 grams was obtained from the -4mm coal samples, and was ground to -1mm in a Sponge coffee grinder, using the method outlined by Newman J. 1985 (part of this sample was latter milled to a fine powder for ash analyses).

b) A further sub-sample of 10-15g was then obtained using a sample micro-splitter, and was mixed with an equal amount of Lucite thermoplastic resin.

c) The mixture was then poured into a Leco RR-10 mounting press, and heated to 120 degrees Celsius at approximately 1 P.S.I. for 20 minutes.

d) The sample was then quickly pressurised to 4200 P.S.I., and cooled to room temperature using a water jacket cooler.

e) Samples were then labeled, and polished using successively finer carborundum paper, then a thick chrome oxide slurry on a rotary polishing wheel, with final polishing occurring with a thick magnesium oxide slurry on a Dewmet selvyt cloth following the method of Newman J. 1985. Samples were cleaned during all stages of the polishing process using detergent and water.

The preparation temperature used in this method exceeds the 100 degrees Celsius recommended by I.C.C.P. guidelines for vitrinite reflectance studies. However, a comparison of low (liquid resin method) and high (Leco press method) temperature mountings of bituminous coals by Newman J. 1986, has shown that no statistical difference is produced in vitrinite reflectance by the two mounting processes.

APPENDIX 5

Maceral Analyses.

Sample U.C.No.	11804	11805	11806	11807	11808	11809	11810	11811	11812
MACERAL GROUP mmf									
Vitrinite	86	not determined	not determined	86	86	86	not determined	79	95
Exinite	9			11	11	11		18	2
Inertinite	5			5	3	4		3	1
MACERAL/SUBMACERALS									
Vitrinite Macerals									
Telocollinite	28			30	32	28		66	81
Desmocollinite	36			7	40	47		9	14
Vitrocollinite	19			5	11	10		1	1
Corpocollinite	0			0	tr	1		0	0
Exinite Macerals									
Liptodetrinite	2			tr	2	1		1	1
Sporinite	tr			tr	tr	1		tr	0
Cutinite	2			3	4	3		1	tr
Resinite	2			1	0	1		14	tr
Suberinite	3			2	5	5		1	1
Fluorinite	0			0	0	0		0	0
Inertinite Macerals									
Inertodetrinite	3			1	0	2		1	1
Semifusinite	1			1	3	1		1	tr
Fusinite	0			0	0	0		0	0
Macrinite	0			0	0	0		0	0
Sclerotinite	1			1	0	1		1	tr
MINERAL MATTER									
quartz	0			1	tr	0		0	7
clay	3			47	5	tr		2	1
pyrite	0			0	0	0		2	0
hematite	0			0	0	0		0	0
lipto/clay	0			0	0	0		0	0
reworked peat	0			3	0	0		tr	0
TPI (Newman)	0.51			2.33	0.62	0.49		6.90	5.40
Thickness		0.05m	0.02m				Grab sample		
Coal Type	Type D	N.D.	N.D.	Type D	Type D	Type D	N.D.	Type AB A	Type AB A
Member	Donkey	Donkey	Donkey	Donkey	Donkey	Donkey	Camp	Donkey	Donkey
Grid Ref.	L30 108075	L30 108075	L30 108075	L30 108075	L30 108075	L30 108075	L30 169181	L30 108077	L30 108077

Sample U.C.No.	11813	11814	11815	11816	11817	11818	11819	11820	11821
MACERAL GROUP mmf									
Vitrinite	92	84	77		75	79	83	76	89
Exinite	16	12	21		20	16	9	11	10
Inertinite	2	5	3		5	4	-	13	4
MACERAL/SUBMACERALS									
Vitrinite Macerals									
Telocollinite	52	21	25	22	25	21	21	22	37
Desmocollinite	24	52	45	45	33	22	49	49	33
Vitrocollinite	1	6	1	6	2	1	9	2	tr
Corpocollinite	2	tr	0	1	0	0	tr	tr	tr
Exinite Macerals									
Liptodetrinite	9	4	14	7	11	4	5	5	6
Sporinite	1	1	1	1	1	1	1	2	tr
Cutinite	2	3	2	2	1	2	1	tr	2
Resinite	1	2	1	1	2	1	1	2	tr
Suberinite	2	1	1	2	0	2	tr	1	0
Fluorinite	0	0	0	0	0	0	0	0	0
Inertinite Macerals									
Inertodetrinite	tr	2	1	1	1	tr	2	3	1
Semifusinite	tr	1	1	1	1	tr	1	1	tr
Fusinite	0	0	0	Tr	0	0	0	0	0
Macrinite	0	0	0	0	0	0	0	0	0.
Sclerotinite	2	2	1	Tr	3	2	3	8	tr
MINERAL MATTER									
quartz	0	0	2	2	2	4	0	1	2
clay	3	6	3	10	15	40	7	3	15
pyrite	2	1	2	Tr	0	1	tr	0	1
hematite	0	0	0	Tr	0	0	1	1	tr
lipto/clay	0	0	0	0	0	0	0	0	0
reworked peat	tr	0	1	1	1	1	tr	0	0
TPI (Newman)	2.03	0.38	0.55	0.43	0.76	0.93	0.36	0.43	1.10
Thickness				0.15m	0.09m	0.15m	0.5m	0.30m	0.25m
Coal Type	Type AB A	Type AB B	Type AB B		carbominerite	carbominerite	Type AB	Type AB	Type Cd
Member	Donkey	Donkey	Donkey	Giles Fm	Camp	Camp (fine)	Thomson	Thomson	Camp
Grid Ref.	L30 109077	L30 108077	L30 108077	K30 097058	L30 218191	L30 229192	L29 208204	L29 231237	L29 250203

Sample U.C.No.	11822	11823	11824	11825	11826	11827	11628	11829	11830
MACERAL GROUP mmf									
Vitrinite	86	71	83	87	83	75	97	72	86
Exinite	11	23	11	12	10	23	2	28	13
Inertinite	4	6	5	2	8	4	0	1	2
MACERAL/SUBMACERALS									
Vitrinite Macerals									
Telocollinite	23	26	31	23	19	30	89	38	29
Desmocollinite	42	35	36	37	42	35	2	26	41
Vitrocollinite	14	2	15	23	19	7	tr	1	15
Corpocollinite	tr	0	tr	0	tr	tr	tr	1	1
Exinite Macerals									
Liptodetrinite	4	17	4	4	4	8	0	8	5
Sporinite	tr	1	1	1	1	1	0	1	1
Cutinite	1	2	1	1	1	9	tr	13	2
Resinite	2	1	1	1	3	1	0	2	2
Suberinite	2	1	4	4	1	2	2	1	3
Fluorinite	0	0	0	0	0	0	0	0	0
Inertinite Macerals	.								
Inertodetrinite	1	2	3	1	3	1	tr	0	1
Semifusinite	1	1	1	tr	1	1	0	0	tr
Fusinite	0	0	0	0	0	0	0	0	0
Macrinite	0	0	0	0	0	0	0	0	0
Sclerotinite	1	2	1	1	2	1	0	1	1
MINERAL MATTER									
quartz	3	2	1	1	0	0	0	1	0
clay	5	7	1	3	2	2	6	7	1
pyrite	tr	0	0	0	1	2	tr	1	0
hematite	0	0	0	0	0	0	0	0	0
lipto/clay	0	0	0	0	1	0	0	0	0
reworked peat	1	2	tr	1	0	1	0	tr	tr
TPI (Newman)	0.42	0.58	0.60	0.39	0.32	0.72	47.5	1.37	0.52
Thickness	2m	0.08m			0.30m	0.05m	0.05	0.04m	0.04m
Coal Type	Type AB-D	Type Cd	Type D	Type D	Type AB	Type C	a log A	Type C	Type Co
Member	Donkey	Camp	Donkey	Donkey	Thomson	Camp	Camp	Thomson	Camp
Grid Ref.	L30 108075	L29 210202	K30 092063	K30 092063	L29 213213	L29 240204	L29 265228	L29 264229	L29 225221

Sample U.C.No.	11831	11832	11833	11834	11835	11836	11837	11838	11839
MACERAL GROUP mmf									
Vitrinite	75	65	80	62	87	76	73	79	80
Exinite	20	32	15	27	10	18	22	18	15
Inertinite	5	3	5	13	2	8	2	3	5
MACERAL/SUBMACERALS									
Vitrinite Macerals									
Telocollinite	25	29	12	12	33	14	24	12	16
Desmocollinite	37	29	51	31	31	46	33	25	51
Vitrocollinite	5	6	13	16	3	1	2	2	10
Corpocollinite	0	0	1	1	0	0	0	0	1
Exinite Macerals									
Liptodetrinite	12	15	6	12	2	10	14	3	9
Sporinite	2	1	3	2	tr	2	2	tr	1
Cutinite	2	10	3	4	1	1	2	4	3
Resinite	2	1	2	7	1	1	1	0	2
Suberinite	1	3	1	1	2	0	0	2	tr
Fluorinite	0	0	0	0	0	0	tr	0	0
Inertinite Macerals									
Inertodetrinite	2	1	3	6	0	1	tr	0	1
Semifusinite	1	1	1	1	1	tr	1	2	1
Fusinite	0	0	0	0	0	tr	0	0	0
Macrinite	0	0	0	0	0	0	0	0	0
Sclerotinite	2	1	2	6	1	3	1	0	3
MINERAL MATTER									
quartz	1	0	0	0	2	2	1	9	tr
clay	6	2	2	3	18	17	15	40	1
pyrite	1	tr	tr	0	tr	1	2	tr	0
hematite	tr	0	1	0	2	0	0	0	0
lipto/clay	0	0	0	0	tr	0	0	0	tr
reworked peat	1	1	0	tr	2	1	1	2	1
TPI (Newman)	0.61	0.91	0.20	0.24	0.98	0.29	0.67	0.42	0.25
Thickness	0.30m	0.25m	0.25m	0.35m	0.03m	0.35m	0.10m	0.10m	0.15m
Coal Type	N.D.	Type C	Type AB	Type AB	Type AB	N.D.	Type Cd	carbominerite	Type Co
Member	Thomson	Camp	Thomson	Thomson	Thomson	Thomson	Thomson	Giles Formation	Camp
Grid Ref.	L29 284247	L29 212205	L29 260229	L29 256254	L29 205205	L29 251224	L29 261221	K30 085053	L29 262220

Sample U.C.No.	11840	11841	11842	11843	11844	11845	11846	11847	11848
MACERAL GROUP mmf									
Vitrinite	77	83	87	73	82	76	76	70	80
Exinite	17	13	10	25	14	21	23	25	15
Inertinite	5	5	4	5	4	2	2	4	4
MACERAL/SUBMACERALS									
Vitrinite Macerals									
Telocollinite	16	7	10	6	11	46	45	11	16
Desmocollinite	45	60	33	31	44	23	24	49	47
Vitrocollinite	3	14	13	0	20	2	3	4	7
Corpocollinite	tr	1	tr	0	tr	tr	1	tr	2
Exinite Macerals									
Liptodetrinite	6	5	3	9	3	4	5	20	12
Sporinite	2	1	tr	0	1	tr	tr	0	tr
Cutinite	2	3	1	1	3	14	13	2	1
Resinite	1	2	2	3	5	1	2	1	1
Suberinite	3	2	tr	1	1	1	1	0	1
Fluorinite	0	0	0	0	0	0	0	0	0
Inertinite Macerals									
Inertodetrinite	tr	1	tr	tr	0	1	1	tr	1
Semifusinite	1	1	2	1	1	0	tr	1	tr
Fusinite	0	0	0	0	0	0	0	tr	0
Macrinite	0	0	0	0	0	0	0	0	0
Sclerotinite	2	3	tr	1	3	1	1	3	2
MINERAL MATTER									
quartz	3	0	1	10	6	1	tr	1	0
clay	14	1	31	34	2	1	1	9	4
pyrite	1	0	tr	1	tr	2	0	tr	1
hematite	tr	0	tr	tr	0	0	0	0	0
lipto/clay	1	tr	0	1	0	0	0	0	0
reworked peat	1	tr	2	2	0	2	1	tr	4
TPI (Newman)	0.33	0.09	0.22	0.17	0.17	1.95	1.64	0.21	0.30
Thickness	0.07m	0.4m	0.10m		1m	0.08m	0.30m	0.03m	0.15m
Coal Type	Type AB	Type Co	Type AB	carbominerite	Type AB	Type C	Type C	Type AB	Type AB
Member	Thomson	Camp	Thomson	Camp (fine)	Thomson	Camp	Camp	Thomson	Thomson
Grid Ref.	L29 208204	L29225221	L29 218206	L30 255199	L29 208203	L29 213201	L29 211203	L29 208204	L29 243298

Sample U.C.No.	11849	11850	11851	11852	11853	11854	11855	11856	11857
MACERAL GROUP mmf			no sample						
Vitrinite	80	70		84	84	73	78	84	55
Exinite	14	25		14	12	22	14	12	41
Inertinite	6	3		2	3	5	8	4	3
MACERAL/SUBMACERALS									
Vitrinite Macerals									
Telocollinite	9	18		23	17	4	5	8	9
Desmocollinite	65	42		53	47	28	52	56	31
Vitrocollinite	4	2		3	14	3	4	1	1
Corpocollinite	1	1		1	2	0	1	1	0
Exinite Macerals									
Liptodetrinite	5	20		7	6	10	8	9	28
Sporinite	tr	1		0	tr	0	1	1	0
Cutinite	4	1		2	tr	0	2	1	tr
Resinite	4	1		1	2	0	1	1	1
Suberinite	1	1		1	4	0	tr	0	tr
Fluorinite	0	0		0	0	0	0	0	0
Inertinite Macerals									
Inertodetrinite	1	tr		tr	tr	tr	4	tr	1
Semifusinite	1	tr		tr	1	1	1	1	0
Fusinite	0	0		0	0	0	0	0	0
Macrinite	0	0		0	0	0	0	0	0
Sclerotinite	4	3		1	2	2	3	2	2
MINERAL MATTER									
quartz	tr	tr		0	tr	6	1	1	4
clay	1	7		2	1	45	2	6	22
pyrite	tr	0		1	tr	1	3	tr	0
hematite	0	0		0	0	0	tr	tr	0
lipto/clay	0	1		2	tr	tr	1	2	2
reworked peat	1	1		1	3	0	1	tr	tr
TPI (Newman)	0.11	0.42		0.41	0.27	0.12	0.07	0.12	0.28
Thickness	1.3m	1.9m		0.1m		0.08m	0.30m	0.25m	0.04m
Coal Type	Type Co	Type AB		Type Co	Type D	carbominerite	N.D.	Type Cd	Type Cd
Member	Camp	Donkey		Thomson	Donkey	Camp	Camp	Donkey	Camp
Grid Ref.	L29 233221	L30 108075		L29 262221	K30 090063	L30 218191	L30 228193	K30 091060	L29 238207

Sample U.C.No.	11858	11859	11860	11861	11862	11863	11864	11865
MACERAL GROUP mmf								
Vitrinite	75	73	80	79	87	69	85	78
Exinite	21	24	17	19	10	23	10	16
Inertinite	5	4	4	2	4	8	5	5
MACERAL/SUBMACERALS								
Vitrinite Macerals								
Telocollinite	12	13	21	31	33	14	21	14
Desmocollinite	53	50	47	40	41	33	53	46
Vitrocollinite	4	2	9	5	10	19	7	16
Corpocollinite	1	tr	1	2	3	2	1	1
Exinite Macerals								
Liptodetrinite	5	16	9	13	5	9	3	4
Sporinite	2	tr	1	0	0	1	1	1
Cutinite	1	2	2	2	1	4	2	1
Resinite	12	tr	5	3	3	7	3	9
Suberinite	tr	tr	tr	1	1	2	1	1
Fluorinite	0	0	0	0	0	0	0	0
Inertinite Macerals								
Inertodetrinite	0	1	1	tr	2	3	1	1
Semifusinite	3	1	1	0	tr	tr	tr	1
Fusinite	0	0	0	0	0	0	0	0
Macrinite	0	0	0	0	0	0	0	0
Sclerotinite	2	1	2	2	2	5	4	4
MINERAL MATTER								
quartz	1	2	0	0	0	0	2	tr
clay	42	6	tr	0	1	1	2	tr
pyrite	tr	2	tr	0	0	0	0	0
hematite	0	1	0	0	0	0	0	0
lipto/clay	0	tr	0	0	tr	0	tr	0
reworked peat	1	1	1	1	tr	1	tr	1
TPI (Newman)	0.20	0.25	0.39	0.69	0.65	0.27	0.35	0.22
Thickness	0.15m	0.15m	0.09m	grab sample	grab sample	grab sample	grab sample	grab sample
Coal Type	Type AB	N.D.	Type AB	N.D.	N.D.	Type AB	Type D	Type D
Member	Thomson	Giles Formation	Camp	Camp	Camp	Camp	Donkey	Donkey
Grid Ref.	L29 208204	K30 097058	L30 156173	L30 156173	L30 156173	L30 158173	L30 115102	L30 126124

Sample U.C.No.	11865	11867	11868	11869	11870	11871	11872	11873	11874
MACERAL GROUP mmf									
Vitrinite	84	82	90	72	82	72	82	76	67
Exinite	9	9	12	19	12	20	13	21	29
Inertinite	6	8	6	11	7	8	5	3	7
MACERAL/SUBMACERALS									
Vitrinite Macerals									
Telocollinite	15	11	19	14	14	16	27	28	16
Desmocollinite	57	17	45	45	55	43	31	36	35
Vitrocollinite	8	45	8	5	9	8	20	5	6
Corpocollinite	1	2	3	2	2	2	1	2	tr
Exinite Macerals									
Liptodetrinite	4	4	6	11	5	7	2	5	9
Sporinite	1	1	1	1	2	3	2	2	5
Cutinite	1	2	1	1	2	8	4	10	6
Resinite	2	1	2	3	2	1	4	1	3
Suberinite	1	1	1	1	tr	tr	1	0	tr
Fluorinite	0	0	0	0	0	0	0	0	0
Inertinite Macerals									
Inertodetrinite	1	1	2	4	3	3	1	1	1
Semifusinite	2	3	1	tr	tr	tr	tr	tr	1
Fusinite	0	0	0	0	0	0	0	0	0
Macrinite	0	0	0	0	0	0	0	0	tr
Sclerotinite	3	4	3	5	4	5	4	2	4
MINERAL MATTER									
quartz	1	1	1	0	0	tr	1	0	2
clay	1	4	5	7	2	3	3	2	10
pyrite	tr	0	2	0	0	1	2	2	2
hematite	0	0	0	0	0	tr	0	0	0
lipto/clay	0	0	1	1	2	2	0	2	1
reworked peat	2	2	1	tr	1	0	tr	tr	1
TPI (Newman)	0.22	0.19	0.33	0.27	0.21	0.32	0.53	0.70	0.38
Thickness	grab sample	grab sample	1.5m	2.65m	4.9m	0.10m	0.2m	1.3m?	0.35m
Coal Type	Type D?	Type D?	Type AB	Type AB	Type AB	Type AB	Type AB	Type C	Type AB
Member	Donkey	Donkey	Donkey	Donkey	Donkey	Thomson	Thomson	Camp	Thomson
Grid Ref.	L30 125124	L30 126124	L30 108077	L30 108075	L30 108075	L29 209204	L29 296257	L29 233226	L23 260224

Sample U.C.No.	11875-8	11879
MACERAL GROUP mmf		
Vitrinite		69
Exinite		28
Inertinite		4
MACERAL/SUBMACERALS		
Vitrinite Macerals		
Telocollinite		16
Desmocollinite		36
Vitrocollinite		1
Corpocollinite		0
Exinite Macerals		
Liptodetrinite		13
Sporinite		3
Cutinite		2
Resinite	reflectance	2
Suberinite	only	1
Fluorinite		0
Inertinite Macerals		
Inertodetrinite		1
Semifusinite		0
Fusinite		0
Macrinite		0
Sclerotinite		2
MINERAL MATTER		
quartz		tr
clay		21
pyrite		0
hematite		0
lipto/clay		2
reworked peat		0
TPI (Newman)		0.43
Thickness	all <0.05m	0.10m
Coal Type	carbominerites/logs	N.D.
Member	-	Thomson
Grid Ref.	see Appendix 1	L2S 213213

<u>Key</u>

Type AB A-A component
TPI (Newman)= Telo/Desmo+Vitrodet

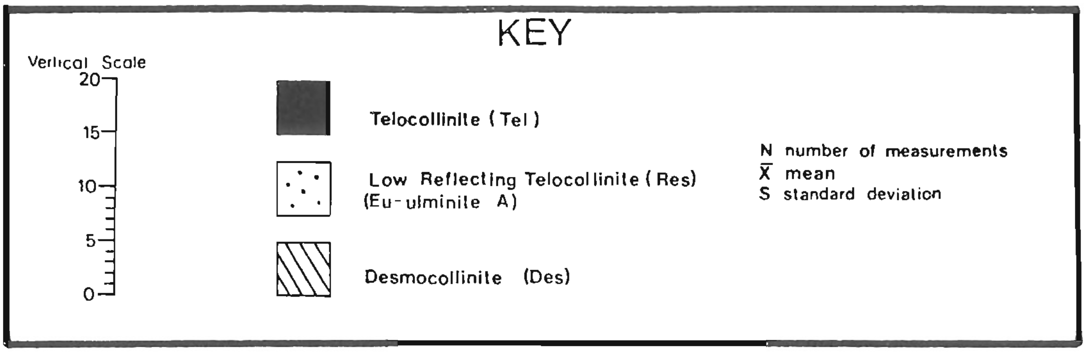
APPENDIX 6

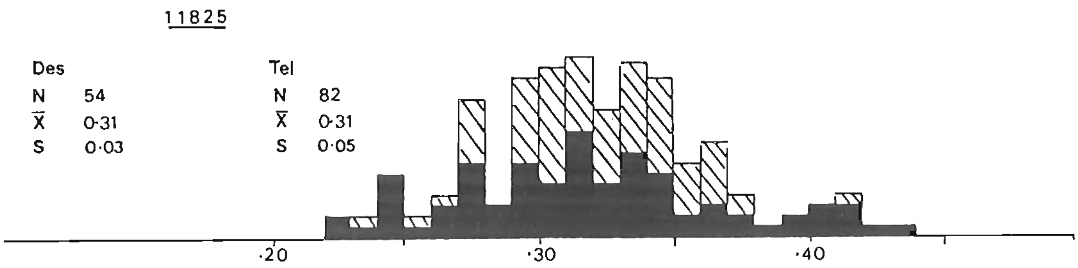
Microlithotype Analyses.

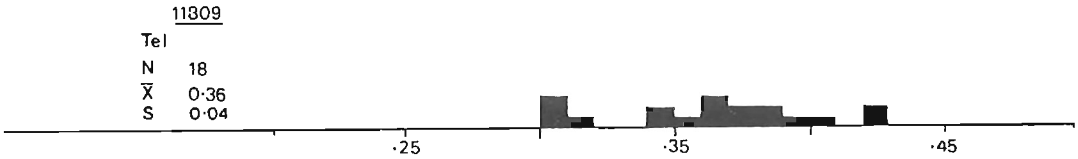
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1) Monomaceral									
vitrite		27	15	21	18	34	37	24	47
liptite	-suberite	tr	1	1	tr	tr	1	3	2
	-resite	3	0	0	0	tr	1	0	1
inertite	-fusite	0	1	0	0	0	0	0	0
	-semifusite	0	tr	0	0	0	0	0	0
	-sclerotite	0	0	0	tr	0	0	tr	tr
2) Bimaceral									
clarite-V	-cuticoclarite-V	8	8	28	31	2	3	13	5
	-sporoclarite-V	2	3	tr	tr	1	2	0	1
	-liptoclarite-V	43	34	26	23	25	21	40	30
clarite-L	-sporoclarite-L	0	0	0	0	0	0	0	0
	-cuticoclarite-L	tr	0	2	1	0	tr	0	0
	-liptoclarite-L	tr	0	1	1	tr	1	1	2
vitrinertite-V	-vitrinertite-V*	2	4	tr	1	7	3	tr	2
	-vitrinsclerotite-V	4	2	2	1	5	6	4	1
vitrinertite-I	-vitrinertite-I*	0	0	0	0	tr	0	tr	0
	-vitrinsclerotite-I	0	1	tr	tr	tr	tr	1	0
durite		0	0	0	0	0	tr	0	0
3) Trimaceral									
duroclarite	-durosporoclarite	1	tr	0	tr	1	3	tr	0
	-duroliptoclarite	6	14	9	7	7	11	9	7
	-duroinertoclarite	4	3	2	1	2	4	3	1
vitrininertoliptite		0	0	2	0	0	tr	0	0
clarodurite		0	0	tr	0	0	0	0	tr
carbominerite	-carbargilite	tr	1	3	5	tr	1	1	tr
	-carbopyrite	0	3	2	8	13	6	0	0
	-carbosilicate	0	tr	0	0	0	0	tr	0
	-carbopolyminerite	0	9	0	1	0	0	tr	0

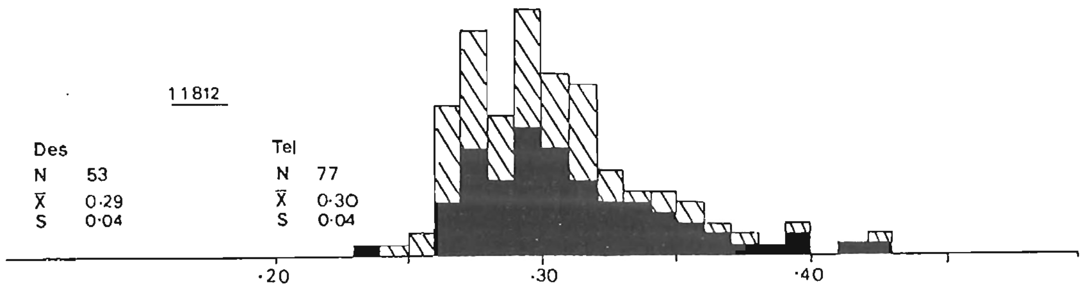
* All inerts other than sclerotite.

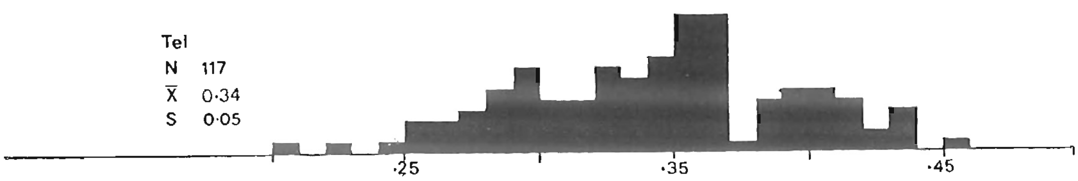
APPENDIX 7 (Reflectance Data)











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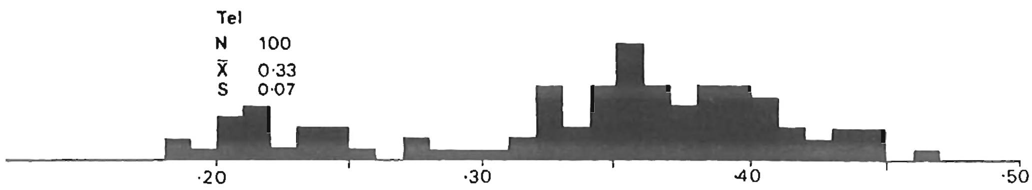

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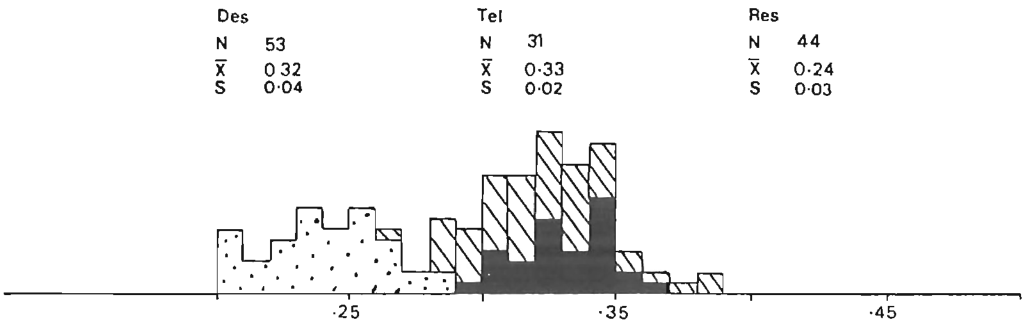

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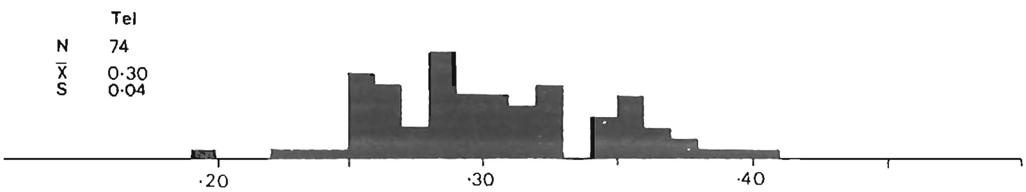

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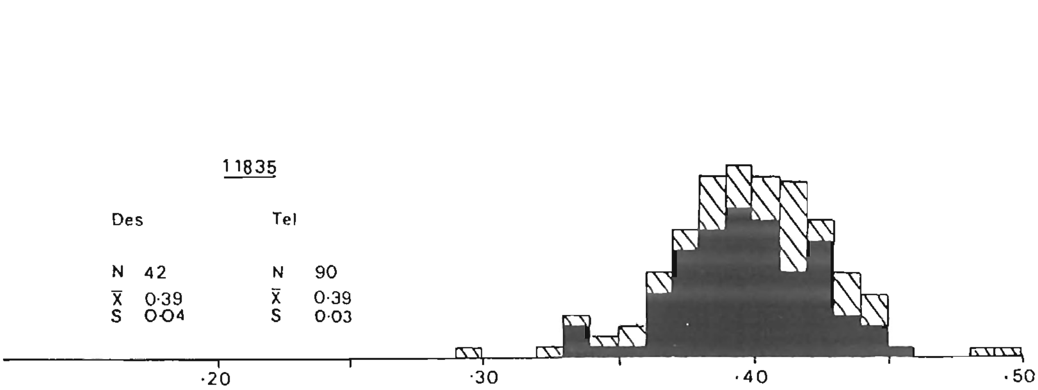

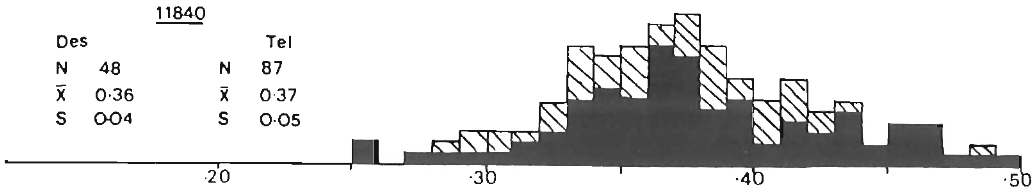
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S 0·04
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S 0·05
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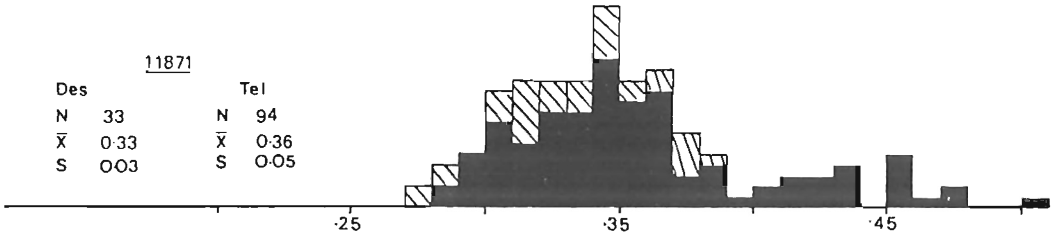
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S 0·03
Tel
N 94
X̄ 0·36
S 0·05
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·35
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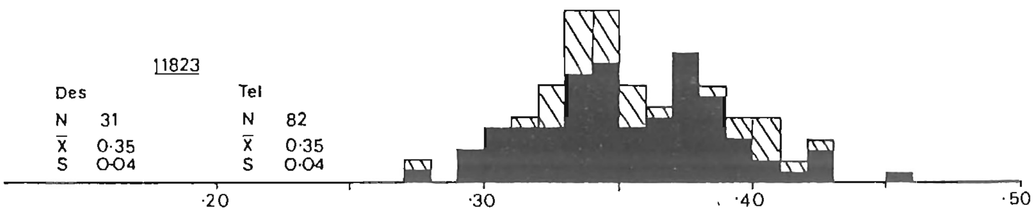
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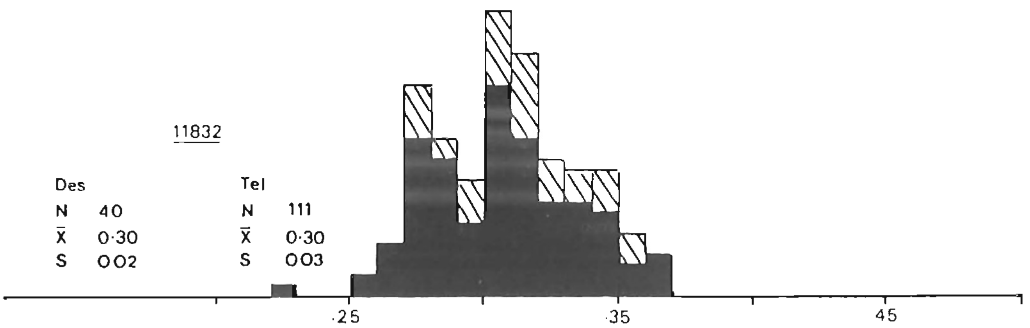
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N 111
X̄ 0·30
S 0·03
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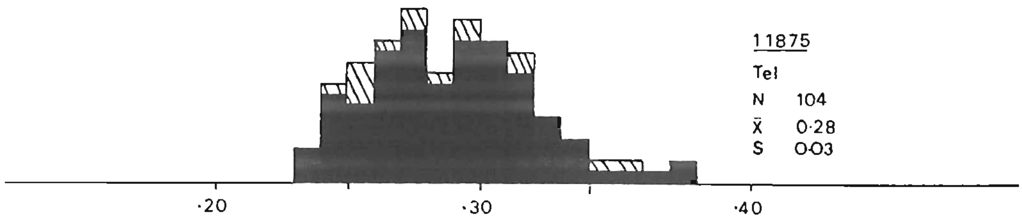

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Tel
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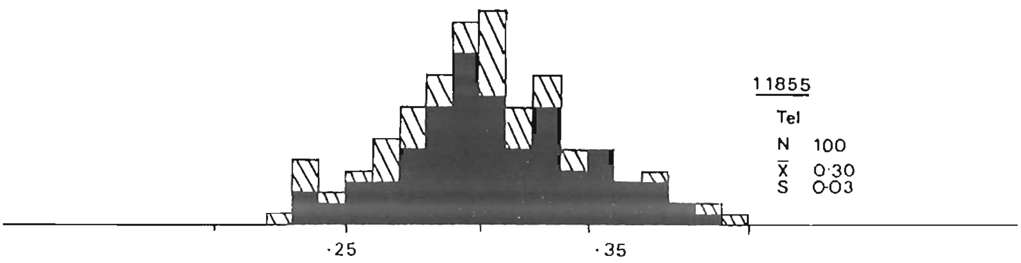

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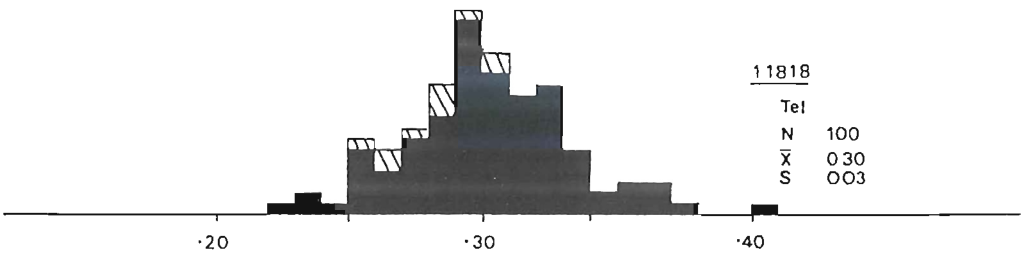

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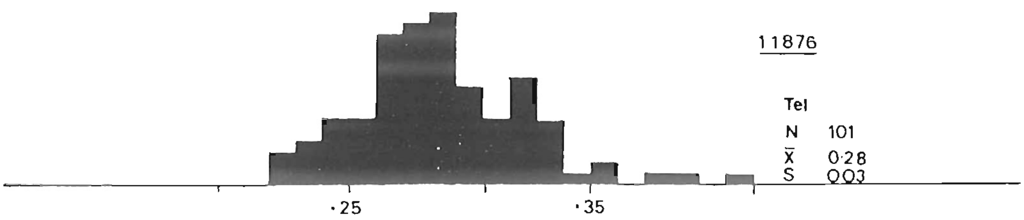

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Tel
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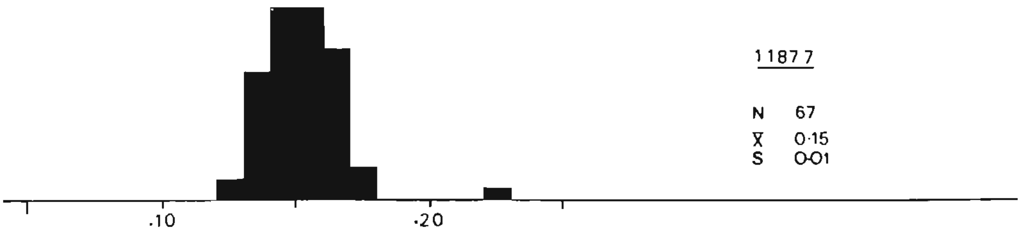
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S 0·01
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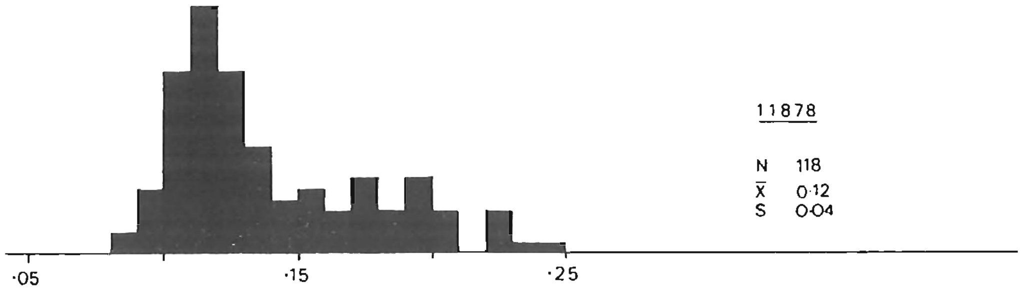
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N 118
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S 0·04
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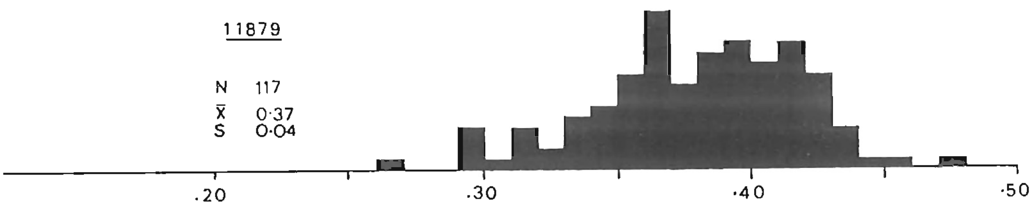
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N 117
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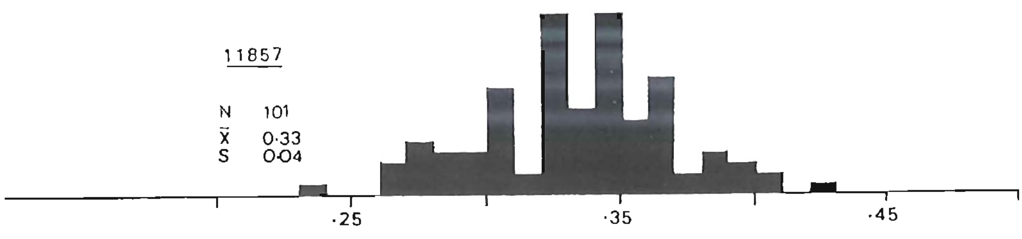
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N 101
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S 0·04
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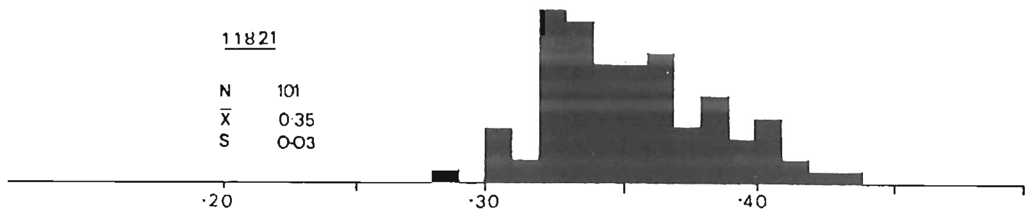
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S 0·03
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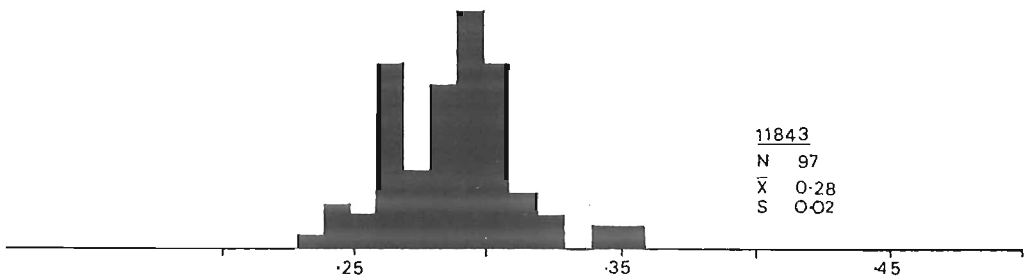
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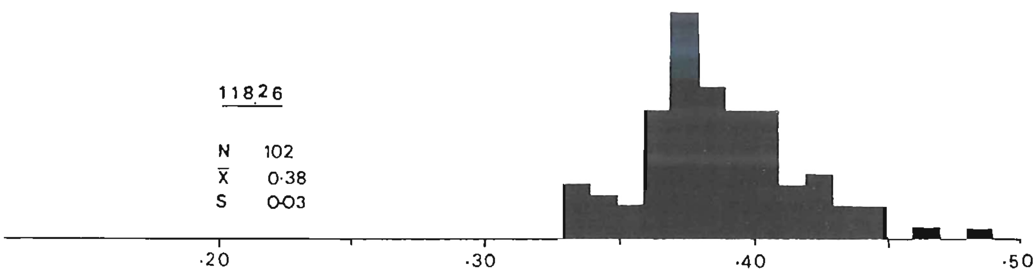
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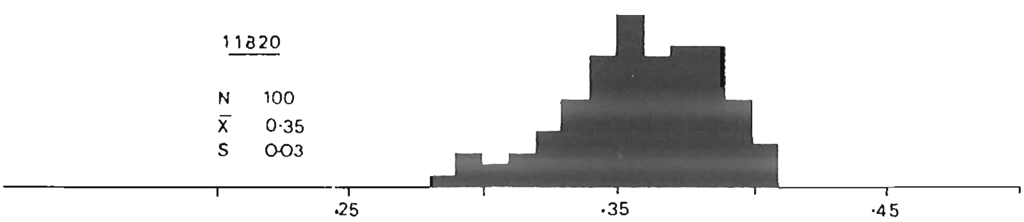
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S 0·03
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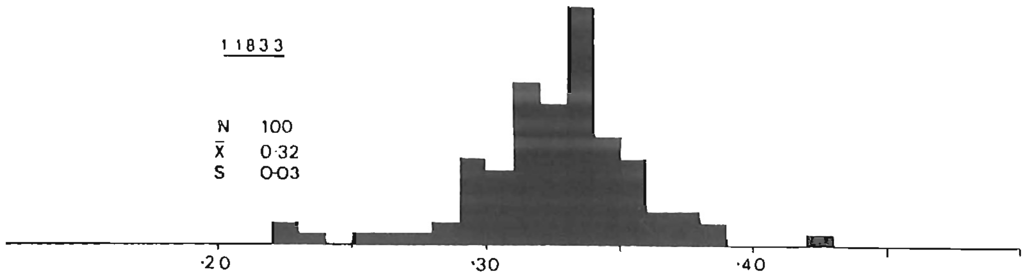
·35
·45


11833
N 100
X̄ 0·32
S 0·03
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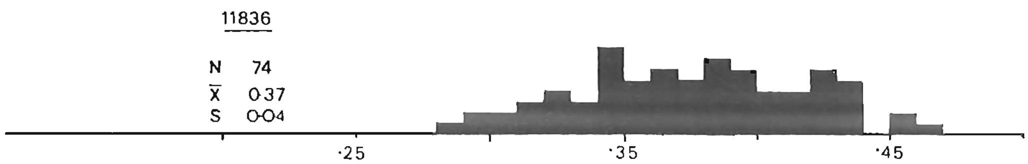
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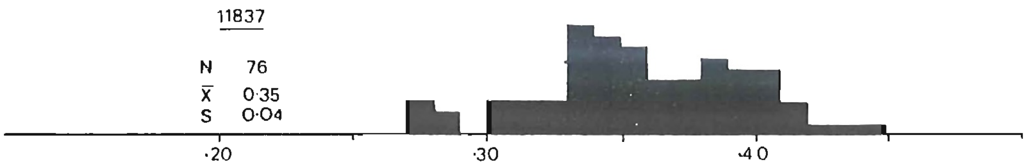
11837
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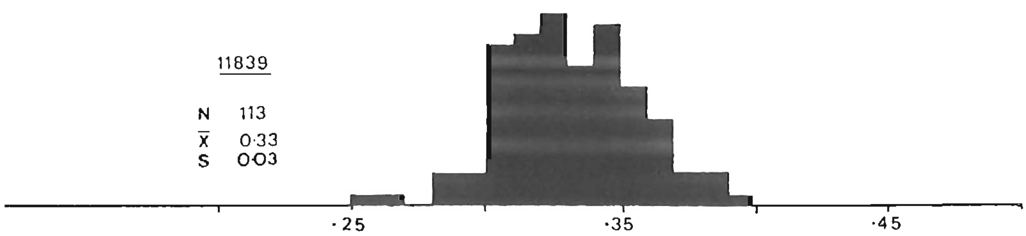
11839
N 113
X̄ 0·33
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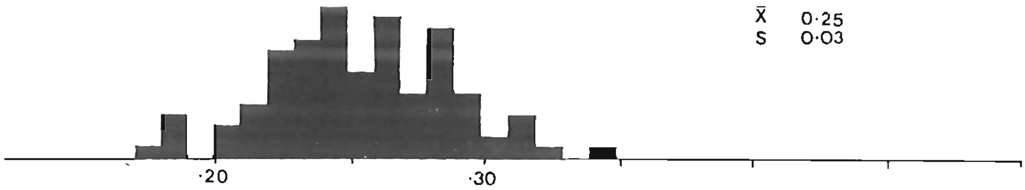
·25
·35
·45

11856

N 101
$\bar{X}$ 0·25
S 0·03



11816

N 101
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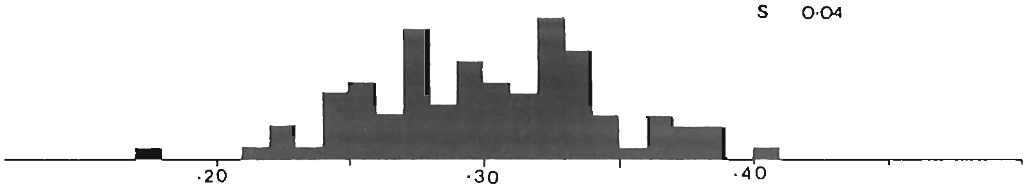
S 0·04



11859

N 79
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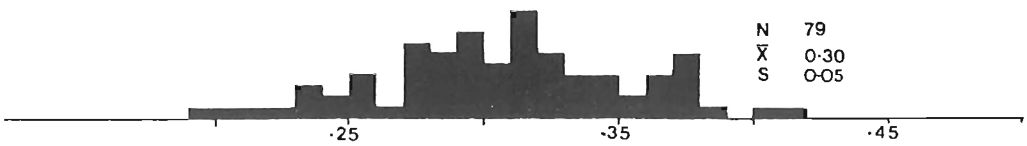
S 0·05



11839

N 72
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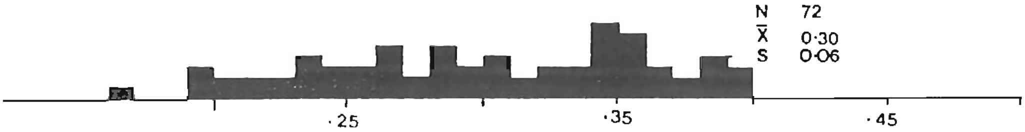

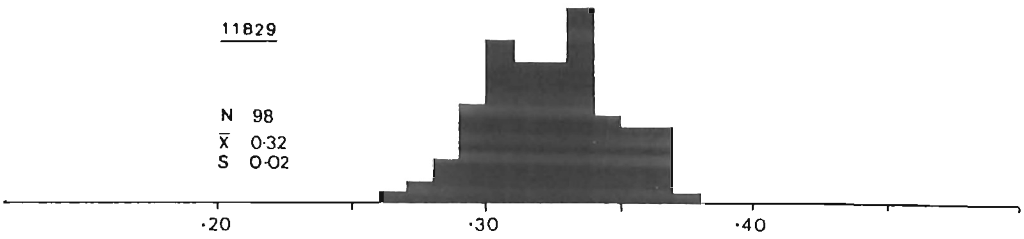
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N 98
X̄ 0·32
S 0·02
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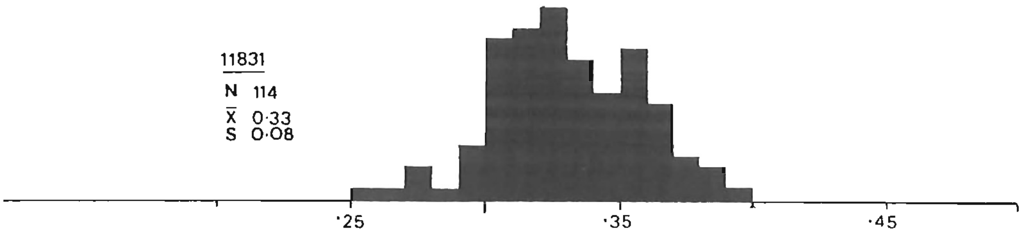
·30
·40


11831
N 114
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S 0·08
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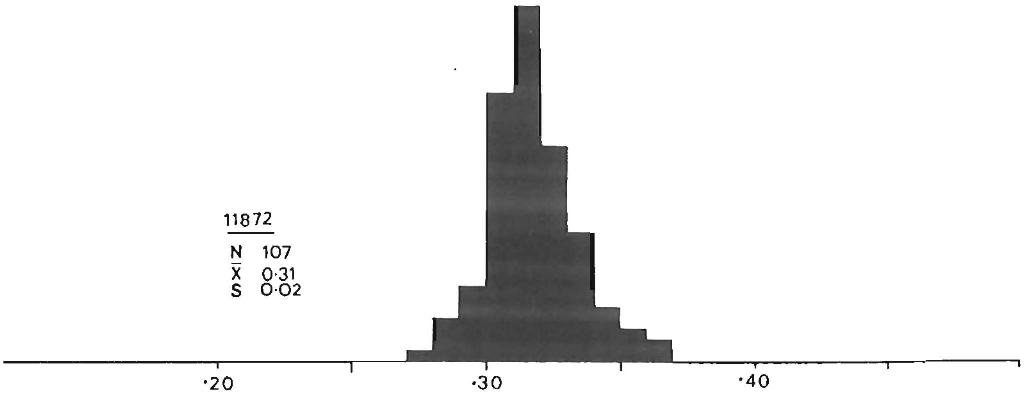
·45


11872
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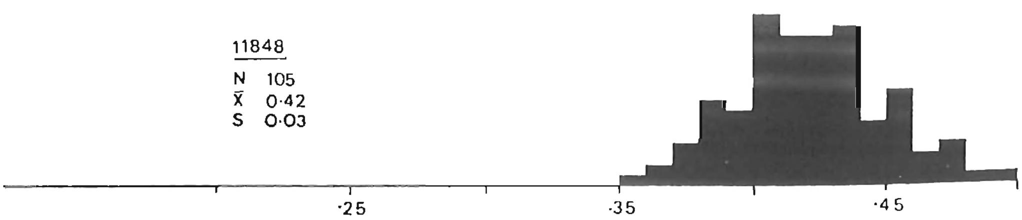
X̄ 0·31
S 0·02
·20
·30
·40


11848
N 105
X̄ 0·42
S 0·03
·25
·35
·45

APPENDIX 8

U.C.No.		11821	11849	11855	11843	11839	11838
Coal Analysis (air dried)							
Moisture	%	18.1	21.6	18.1	8.6	20.4	10.9
Ash	%	19.7	3.7	8.5	55.9	4.8	52.1
Volatile Matter	%	30.3	35.3	37.6	19.2	36.1	21.5
Fixed Carbon	%	31.9	39.4	35.8	16.3	38.7	15.5
Calorific Value							
BTU/lb		7,270	8,770	8,280			
MJ/kg		16.91	20.40	19.27			
Sulphur	%	2.79	0.76	5.52	1.38	1.14	1.88

U.C.No.		11814	11812	11870	11822	11805	11804
Moisture (as received)		22.7	22.0	26.5	23.7	25.0	24.2
Coal Analysis (air dried)							
Moisture	%	17.7	16.8	21.4	19.8	21.3	20.7
Ash	%	3.5	7.3	4.3	6.3	3.3	3.4
Volatile Matter	%	39.1	37.5	36.5	35.5	36.0	35.8
Fixed Carbon	%	39.7	38.4	37.8	38.4	39.4	40.1
Calorific Value							
BTU/lb		9,200	8,870	8,690	8,640	8,860	8,860
MJ/kg		21.39	20.64	20.22	20.10	20.62	20.62
Sulphur	%	3.93	3.20	0.40	0.67	0.61	0.86

U.C.No.		11808	11809	11810	11863	11862	11861	11848
Moisture (as received)		23.6	22.2	21.3	23.6	27.6	22.7	28.4
Coal Analysis (air dried)								
Moisture	%	20.8	19.7	18.9	18.7	19.1	17.9	19.0
Ash	%	2.7	2.1	3.6	2.4	1.6	3.6	10.2
Volatile Matter	%	35.6	36.6	38.3	40.6	38.5	41.0	33.7
Fixed Carbon	%	40.9	41.6	39.2	38.3	40.8	37.5	37.1
Calorific Value								
BTU/lb		8,880	9,280	9,230	9,140	9,050	9,550	8,240
MJ/kg		20.66	21.58	21.48	21.25	21.05	22.21	19.16
Sulphur	%	0.82	0.42	0.70	0.37	0.39	0.59	3.62

COAL RESEARCH ASSOCIATION OF NEW ZEALAND (INC.)

P.O. Box 3041
Wellington

Ph: (04) 666.919
ext. 548

REPORT OF ANALYSIS

SAMPLE:

CRA REF:		37/230	37/231	37/232	37/233	37/234	37/235
SAMPLE REF: UC no.		11879	11841	11859	11837	11829	11872
COAL ANALYSIS: (air-dried basis)							
Moisture	-%	16.9	21.9	16.4	20.1	18.7	16.4
Ash	-%	17.2	4.1	17.4	6.0	10.9	3.5
Volatile Matter	-%	34.6	36.4	35.5	34.6	37.7	39.1
Fixed Carbon	-%	31.3	37.6	30.7	39.3	32.7	41.0
Calorific Value	- Btu/lb	8,120	8,800	7,350	8,790	8,840	9,510
	MJ/kg	18.89	20.46	17.10	20.45	20.57	22.13
Sulphur	-%	0.74	0.63	4.25	1.31	3.70	3.85

CRA REF:		37/224	37/225	37/226	37/227	37/228	37/229
SAMPLE REF: UC no		11825	11873	11823	11827	11826	11832
COAL ANALYSIS: (air-dried basis)							
Moisture	-%	21.2	18.6	17.4	20.2	20.9	19.5
Ash	-%	3.0	3.2	6.7	3.9	3.6	4.8
Volatile Matter	-%	37.7	41.6	40.6	39.2	34.9	40.0
Fixed Carbon	-%	38.1	36.6	35.3	36.7	40.6	35.7
Calorific Value	- Btu/lb	8,880	9,580	9,540	9.310	8.750	9,150
	MJ/kg	20.65	22.29	22.19	21.65	20.35	21.29
Sulphur	-%	0.41	2.26	0.79	1.13	1.93	0.86

31/10/86

COAL RESEARCH ASSOCIATION OF NEW ZEALAND (INC.)

Report of Analysis

Rotokuhu Drilling Programme

Borehole 118 Plies

Coal Analysis - As Received Basis

Depth from (m)	to	Weight kg.	Ply No.	CRA Ref.	Moisture %	Ash %	Volatile Matter %	Fixed Carbon %	Calorific Value MJ/kg	Sulphur %
-		0.405	1	42/725	26.7	4.4	37.8	31.1	19.71	0.43
-		1.010	2	42/726	22.2	5.4	35.3	37.1	20.17	0.42
-		0.900	3	42/727	28.0	5.4	32.0	34.6	18.10	0.39
-		1.395	4	42/728	28.3	6.4	31.3	34.0	17.78	0.35
-		0.640	5	42/729	31.0	6.8	32.6	29.6	16.81	0.32
-		0.310	6	42/730	27.0	3.0	34.7	35.3	19.48	0.39
-		1.400	7	42/731	27.9	7.9	30.9	33.3	17.50	0.37
-		1.245	8	42/732	24.5	22.4	28.3	24.8	13.91	0.30
-		2.915	9	42/733	27.4	11.0	29.3	32.3	16.98	0.39
-		1.145	10	42/734	27.8	8.3	33.0	30.9	17.85	0.47
-		0.275	11	42/735	26.3	10.9	30.7	32.1	17.27	0.50
-		0.520	12	42/736	5.2	73.5				
-		0.175	13	42/737	25.6	29.9	22.6	21.9	11.60	0.51
-		1.230	14	42/738	30.3	4.5	32.0	33.2	18.30	0.44
-		0.850	15	42/739	30.3	3.6	31.9	34.2	18.57	0.36
-		1.185	16	42/740	30.7	3.3	32.2	33.8	18.04	0.35
-		1.090	17	42/741	29.7	3.1	31.9	35.3	18.77	0.35
-		1.190	18	42/742	29.5	4.3	31.6	34.6	18.44	0.39
-		0.985	19	42/743	30.5	3.1	31.9	34.5	18.52	0.37
-		0.590	20	42/744	30.8	4.9	29.7	34.6	17.58	0.36
-		0.578	21	42/745	7.3	64.2				
-		0.800	22	42/746	29.1	8.4	31.7	30.8	17.61	0.48
-		0.955	23	42/747	25.3	5.8	34.0	34.9	19.72	0.82
-		2.160	24	42/748	29.8	10.0	30.3	29.9	17.02	0.55
-		1.495	25	42/749	~~12.1~~	~~56.1~~	10.7	11.1	5.57	0.12
-		1.335	26	42/750	24.4	16.3	35.6	23.7	14.82	0.28
-		1.140	27	42/751	25.5	19.6	26.1	28.8	15.18	0.29
-		1.005	28	42/752	30.3	4.2	30.1	35.4	18.05	0.41
-		0.890	29	42/753	26.8	14.6	26.9	31.7	16.37	0.39
-		1.455	30	42/754	29.9	4.6	31.9	33.6	18.41	0.53
-		0.625	31	42/755	28.6	6.8	31.1	33.5	18.02	0.64
-		0.685	32	42/756	32.1	5.6	28.7	33.6	17.26	0.55
-		0.400	33	42/757	34.3	5.0	28.4	32.3	16.91	0.55
-		0.520	34	42/758	31.3	7.6	28.6	32.5	16.84	0.56
-		1.200	35	42/759	~~10.5~~	71.9	8.3	9.3	4.51	0.14
-		1.810	36	42/760	30.6	5.9	32.5	31.0	18.02	0.70
-		5.450	37	42/761	26.7	8.2	33.2	31.9	17.86	0.50
-		1.990	38	42/762	28.9	4.7	31.8	34.6	18.32	0.50

APPENDIX 9

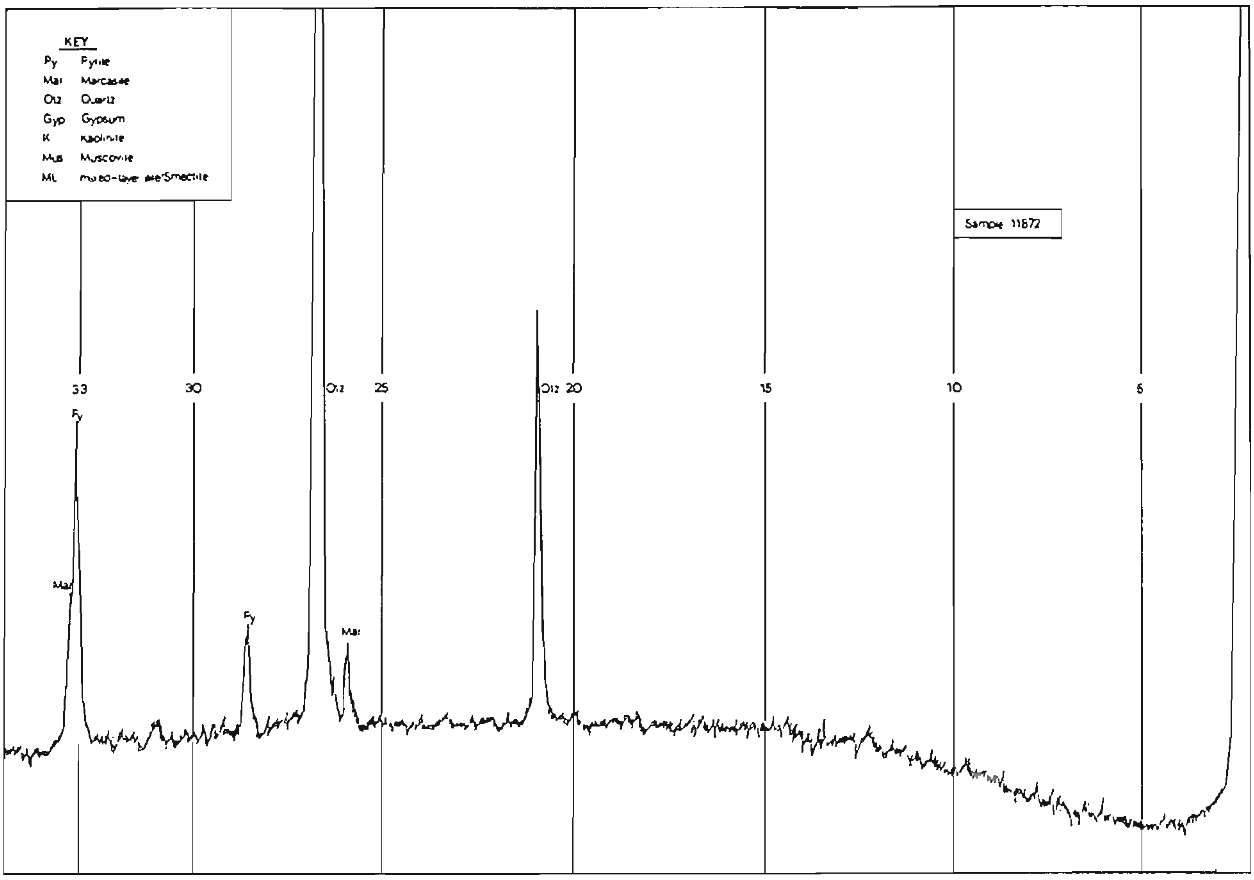
Mineral Matter Present in LTA Residues.

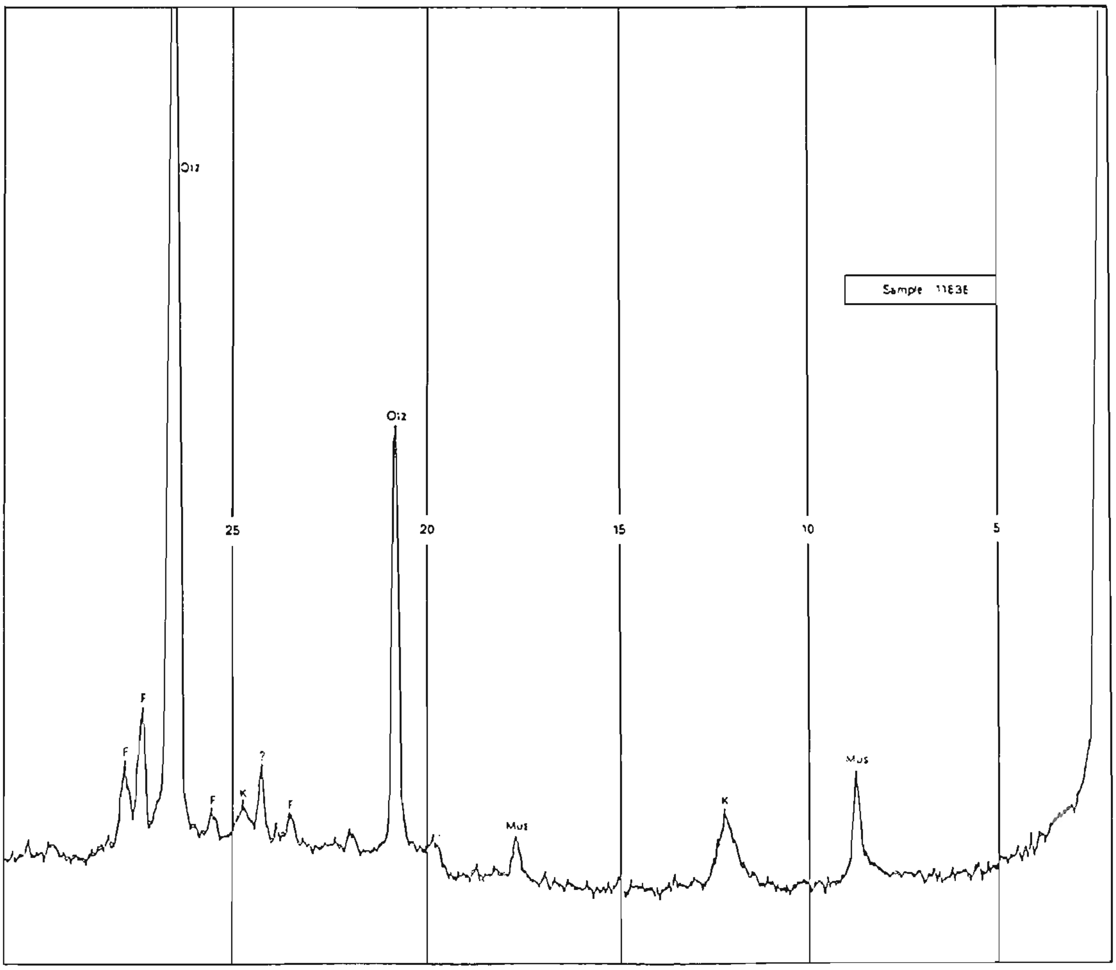
U.C.No.	%Ash	Quartz	Kaolinite	Muscovite/ Illite	Gypsum	Smectite	Pyrite	Marcasite	Feldspar
		Mineral Matter Present in LTA Residues							
11811		Xa	Xa				Xa		
11812	8.8(b)	Xa					Xp		
11882	75 (a)	Xa							
11813		Xa	Xa	Xp	?		Xa		
11814	4.3(b)	Xa	Xa	Xa			Xa		
11815		Xa	Xa				Xa		
11809	2.6(b)	Xa			Xa				
11808	3.4(b)	Xp		Xp					
11804	4.3(b)	Xa			Xa	Xp			
11805	4.2(b)	Xa			Xa				
11806		Xa	Xp			Xa			
11807		Xa	Xp			Xa			
11861	4.4(b)	Xp				?			
11863	3.0(b)	Xa			Xa				
11860		Xa			Xa		Xa		
11810	4.4(b)	Xp			Xp				
11864		X			X				
11825	3.8(b)	Xa			Xa				
11844		Xa			Xa		Xa		
11811		Xa							
11872	4.2(b)	Xa					Xa	Xp	
11926	4.6(b)	Xp	Xp		Xp		Xp		
11623	8.1(b)	Xa	Xp	Xp					
11855	10.4(b)	Xa	Xa	Xa			Xp		
11856		Xa	Xp	Xa			Xa		
11838	58.5(b)	Xa	Xp	Xp		?			Xp
11882		Xa							
11816		Xa	Xp	Xp			Xa		
11818		Xa	Xp	Xa					
11862		no mm detected							

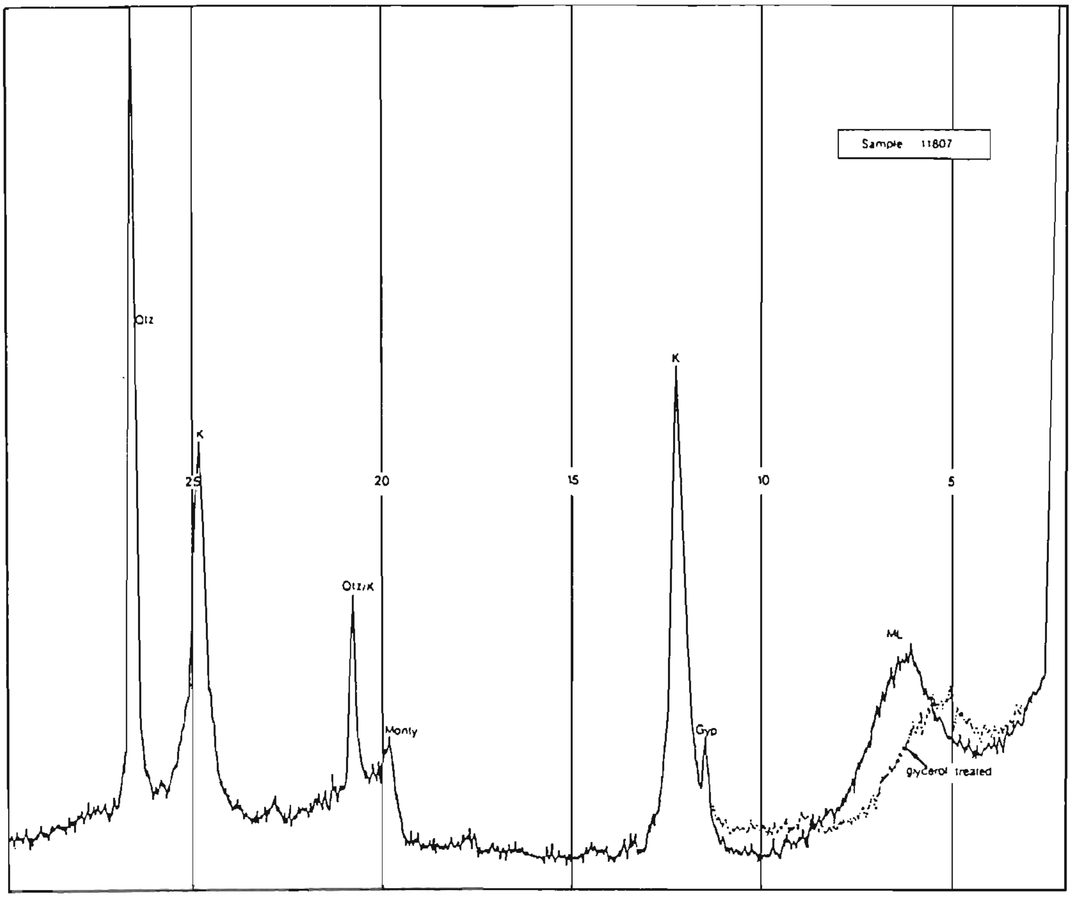
a abundant
p present
(a) Determined approximately during high temperature ashing.
(b) From C.R.A. Proximate Analyses (dry basis).

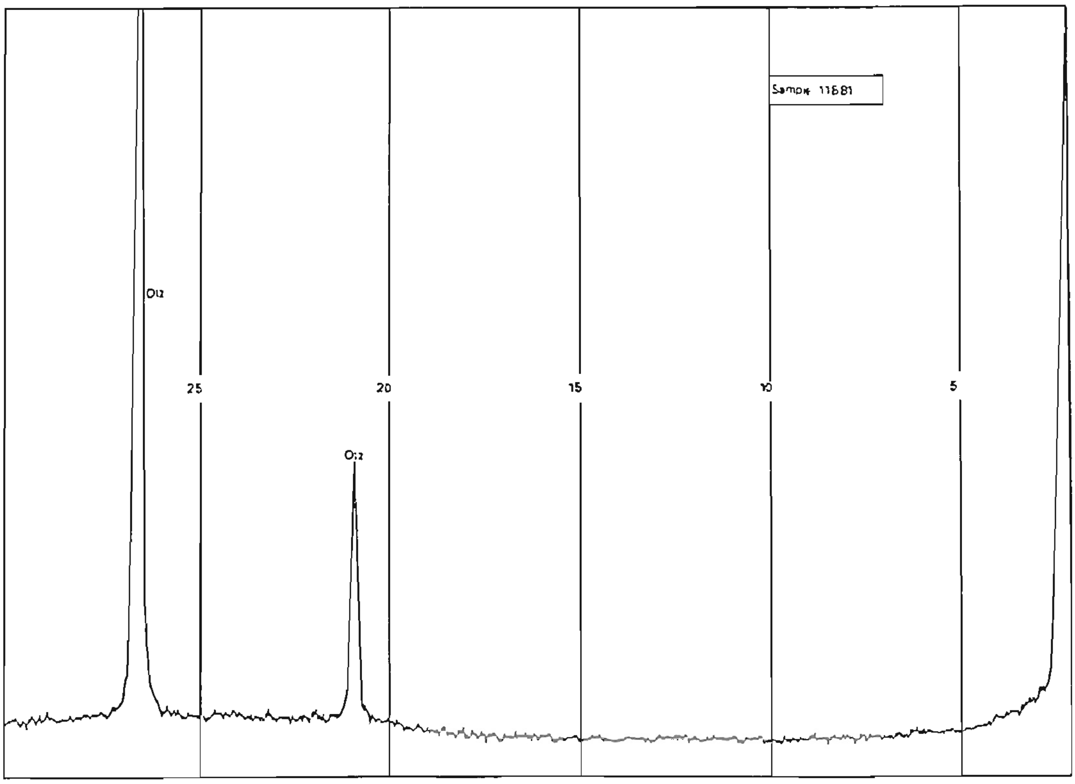
Selected XRD Traces.

APPENDIX 10






Sample 11807
Qtz
K
K
25
20
15
10
5
Qtz/K
Monty
Gyp
ML
glycerol treated


Sample 11881
Qtz
25
20
15
10
5
Qtz

APPENDIX 11

Major Element Chemistry Of Coal Ashes.

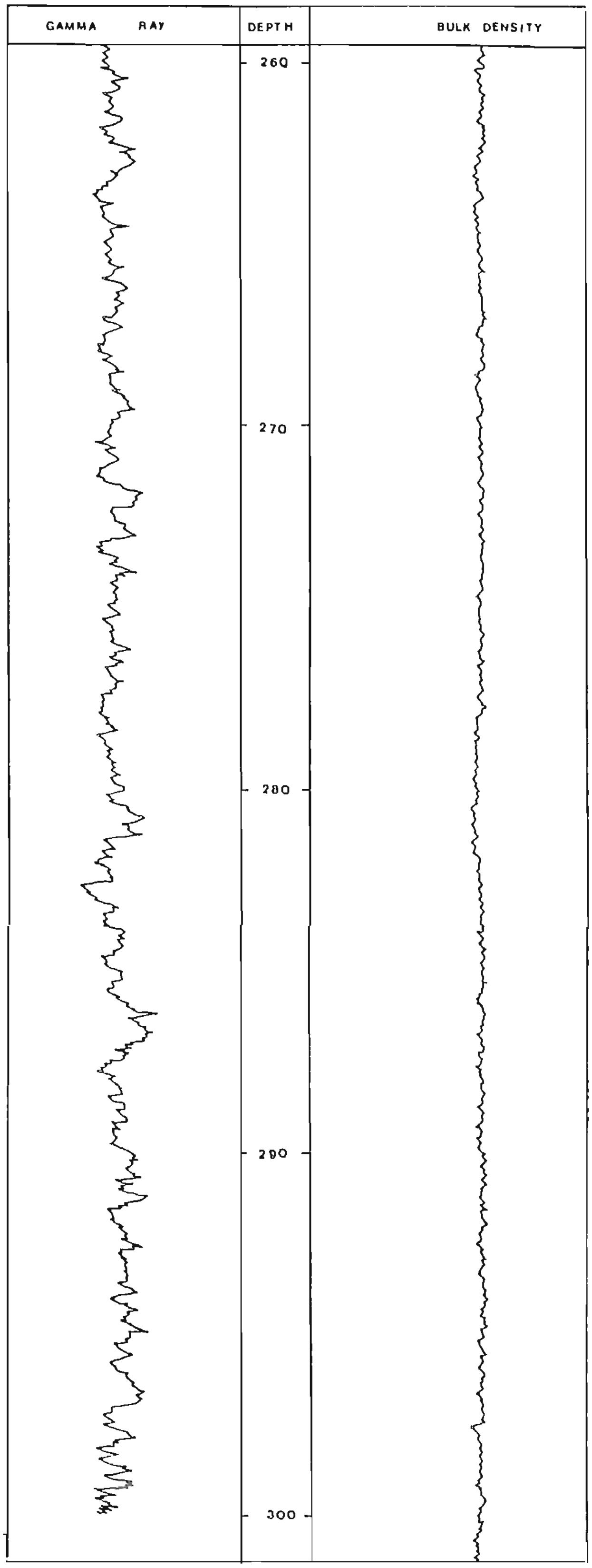
U.C.No.	11812	11813	11816	11818	11823	11825
MgO	0.058	0.359	0.920	1.149	1.429	4.578
Na_2O	0.091	0.007	0.243	0.796	0.133	0.385
SiO_2	89.112	48.027	53.994	61.541	62.665	19.592
Al_2O_3	1.465	22.258	25.275	25.187	24.064	3.700
SS	0.108	0.105	3.080	0.494	1.675	35.485
P_2O_5	0.008	0.038	0.750	0.224	0.045	0.028
Fe_2O_3	8.517	23.559	7.516	4.007	4.000	6.491
MnO	0.029	0.048	0.058	0.021	-0.011	0.058
TiO_2	0.033	1.376	1.281	1.194	1.191	0.081
CaO	0.425	0.615	3.301	0.480	3.257	28.531
K_2O	0.023	1.530	2.755	4.031	2.374	0.187
Total	99.869	97.933	99.183	99.125	100.822	99.117

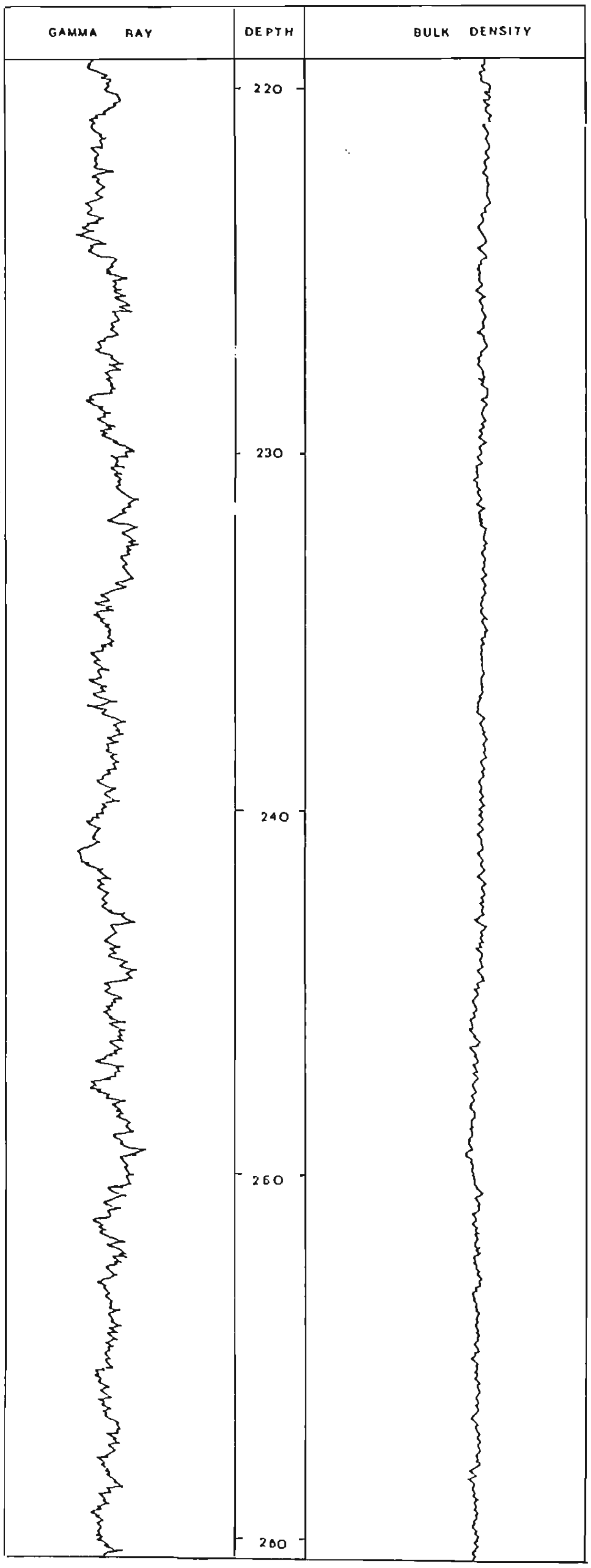
U.C.No.	11826	11838	11844	11855	11856	11862
MgO	3.963	0.481	1.821	0.422	0.417	18.152
Na_2O	1.146	0.515	0.023	0.044	0.106	0.594
SiO_2	9.165	73.865	60.711	39.913	51.650	13.290
Al_2O_3	17.147	13.577	1.457	20.129	27.943	11.293
SS	19.099	3.510	13.829	0.675	1.763	28.764
P_2O_5	0.116	0.038	0.023	1.925	0.060	1.743
Fe_2O_3	38.058	1.845	13.524	32.112	14.035	8.790
MnO	0.155	0.043	0.034	0.045	0.003	0.059
TiO_2	0.167	0.869	0.057	0.869	1.205	0.984
CaO	12.219	3.072	7.924	2.152	0.619	14.574
K_2O	0.193	2.586	0.042	0.956	2.286	0.266
Total	100.502	100.502	99.447	99.242	100.088	98.498

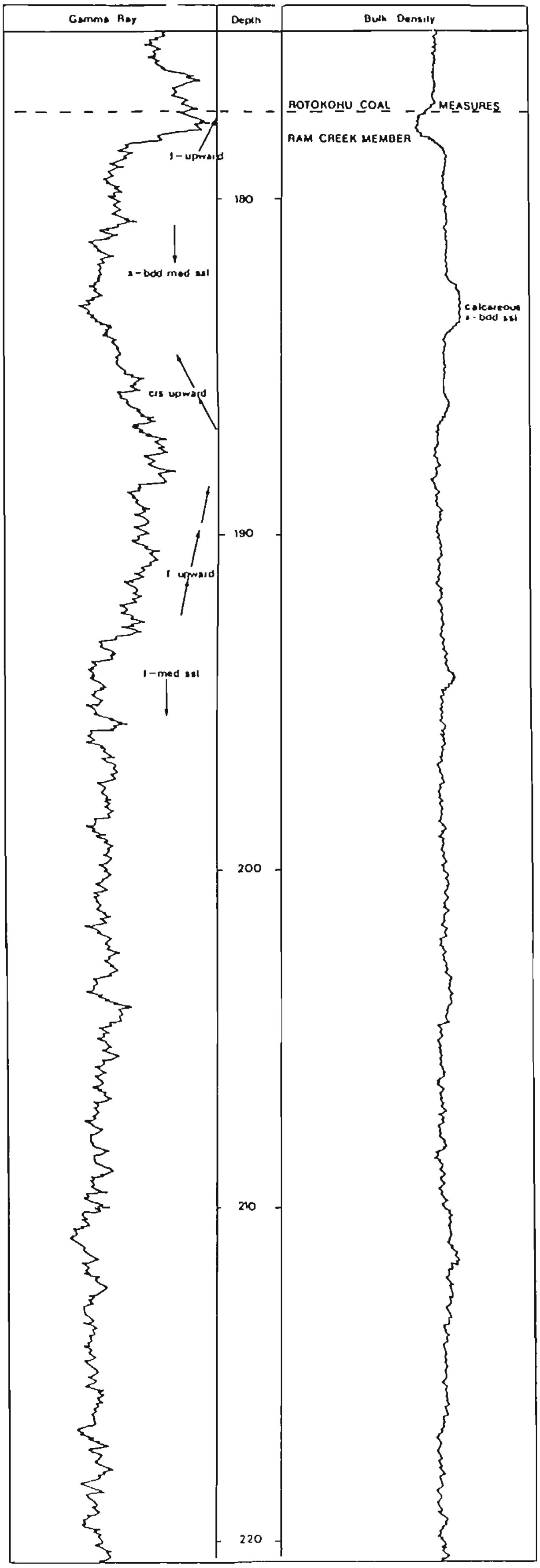
U.C.No.	11864	11872	11881	11882
MgO	8.997	0.402	0.026	0.039
Na_2O	-0.062	0.025	0.075	0.034
SiO_2	33.923	53.485	99.791	100.605
Al_2O_3	1.106	10.320	0.064	0.027
SS	23.237	0.307	0.007	-0.047
P_2O_5	0.025	0.046	0.015	0.004
Fe_2O_3	7.575	29.942	0.249	0.497
MnO	0.076	0.010	0.006	0.040
TiO_2	0.104	0.123	0.006	0.008
CaO	23.999	2.341	0.110	0.009
K_2O	0.117	0.248	0.004	0.000
Total	99.098	97.250	100.353	101.216

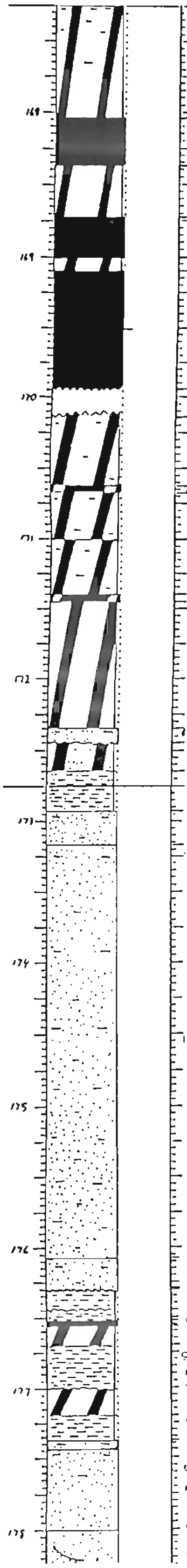
DH 118 Summary Log.

APPENDIX 12




GAMMA RAY
DEPTH
BULK DENSITY
220
230
240
250
260


Gamma Ray
Depth
Bulk Density
ROTOKOHU COAL MEASURES
RAM CREEK MEMBER
f – upward
180
s – bdd med ssl
calcareous
s - bdd ssl
c/s upward
190
f upward
f – med ssl
200
210
220



dusly brn to blk,faintly lam to mass,carb,
micac,Mst,grading up into z Mst/m Zst.

PLY 32.

dk blk-gy brn,mass,carb,Mst.

PLY 33.

brn,carb,Mst.

PLY 34.

PLY 35.
silicified coal.
-less siliceous at top.

core loss.

dusty brn,rpl lam(mass at top),carb,z/s Mst.

blk carb Mst/coal.
dusty brn,rpl lam,z/s carb Mst.

dusty brn,lam-mass,carb,z/s Mst.
-burrowed.

blk carb Mst/dirty coal.

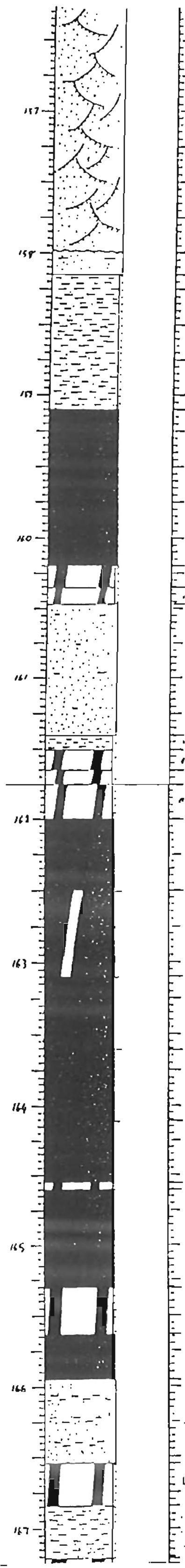
dusty brn,lam-mass,carb,Mst.

brn,rpl lam,prly srt,micac,carb,z f Sst.
dusty brn,lam-mass,carb,sandy micac Mst with
thin micac f Sst beds.

dusty brn,discontinuously lam-mass,carb,f
sandy Zst.
-heavily burrowed.
lt gy,carb,micac,z f Sst.Fining upward.
-burrowed.

lt gy,rpl lam,carb,micac,z f Sst coarsening
up into z f Sst.
-burrowed.
-larger burrows filled with pyrite.
(burrows are however mostly f).

lt gy,lam,carb,micac,z f Sst.
-heavily burrowed.
lt gy to med gy,lam,carb,micac,z f Sst/s Zst.
-heavily burrowed.
med dk gy,finely lam,carb,micac,f sandy Zst.
-burrowed.
gy blk-blk,faintly lam-mass,carb,Mst.
dusty brn,discontinuously lam,f sandy,carb,Zst.
-heavily burrowed.(f)
dusty brn,mass to faintly lam,carb,Mst.
gy brn to dusty brn,mass grading up into
slightly lam,micac,carb-carb,Zst.
-burrowed.
dk yll brn-gy brn,prly srt,micac,carb z f Sst.
med lt gy-g brn gy,prly srt,micac,f-med Sst
fining up into z f Sst.
med lt gy,prly srt,carb,micac,f-med Sst.
shdd in places.
-fining up.



brn gy to lt gy,prly srt,micac,carb,rpl lam and xbdd,z f-med Sst.
-festoon xbdd.

brn gy,prly srt,micac,carb,rpl lam,z f-f Sst.
-burrowed.

-sandier at top.

dusky brn to blk,prly srt,micac-micac,carb,
f sandy m Zst.
-burrowed.

PLY 24.

blk,carb Mst.

dusky brn-blk,faintly lam-mass,carb,Mst.

lt brn gy,mod srt,micac-micac,carb,z f-f Sst.

dusky brn to blk,prly srt,micac-micac,carb,
s Zst.
blk,dirty coal/carb Mst.

dusky brn,carb,Mst.

-partly silicified.

PLY 25.

PLY 26.

PLY 27.

PLY 28.

PLY 29.

blk,carb Mst.

PLY 30.

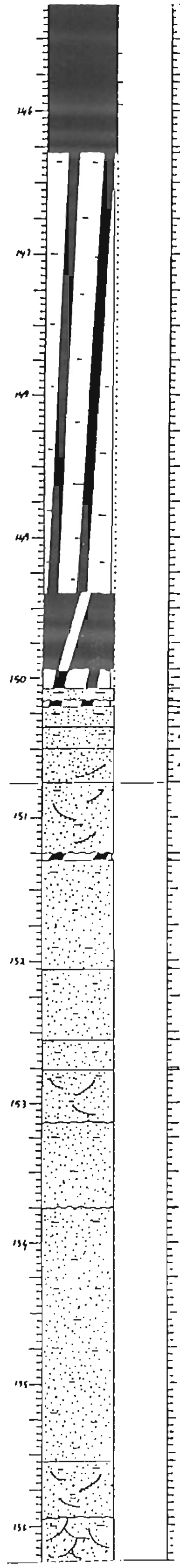
interbedded coal and blk-dusky brn,carb Mst.

PLY 31.

lt gy brn,rpl lam,carb f-f Sst and carb Zst.
-burrowed.

blk,carb,Mst and dirty coal.

lt gy-brn gy,rpl lam,f sandy carb Zst to
z f Sst.
-burrowed.



FLY 19.

FLY 20.
-slightly silicified at base.
FLY 21.
-silicified coal.
FLY 22.

dusty brn to bl,mass-faintly lam,carb,micac,
f sandy Mst and Zst.

FLY 23.

dusty brn,carb,Mst.
lt olv gy,rpl lam,carb,z f Sst.
dusty brn,carb Mst.
lt olv gy,rpl lam-mass,z f Sst,Mst rip-up
clasts.
lt olv gy,rpl lam,micac,carb,z f Sst.
flame structures present.
-burrowed and rooted.

med lt gy,xbdd grading up into rpl lam,carb,
micac,z med-f to f Sst.

bl carb Mst

lt gy,lam,carb,micac,z f Sst.

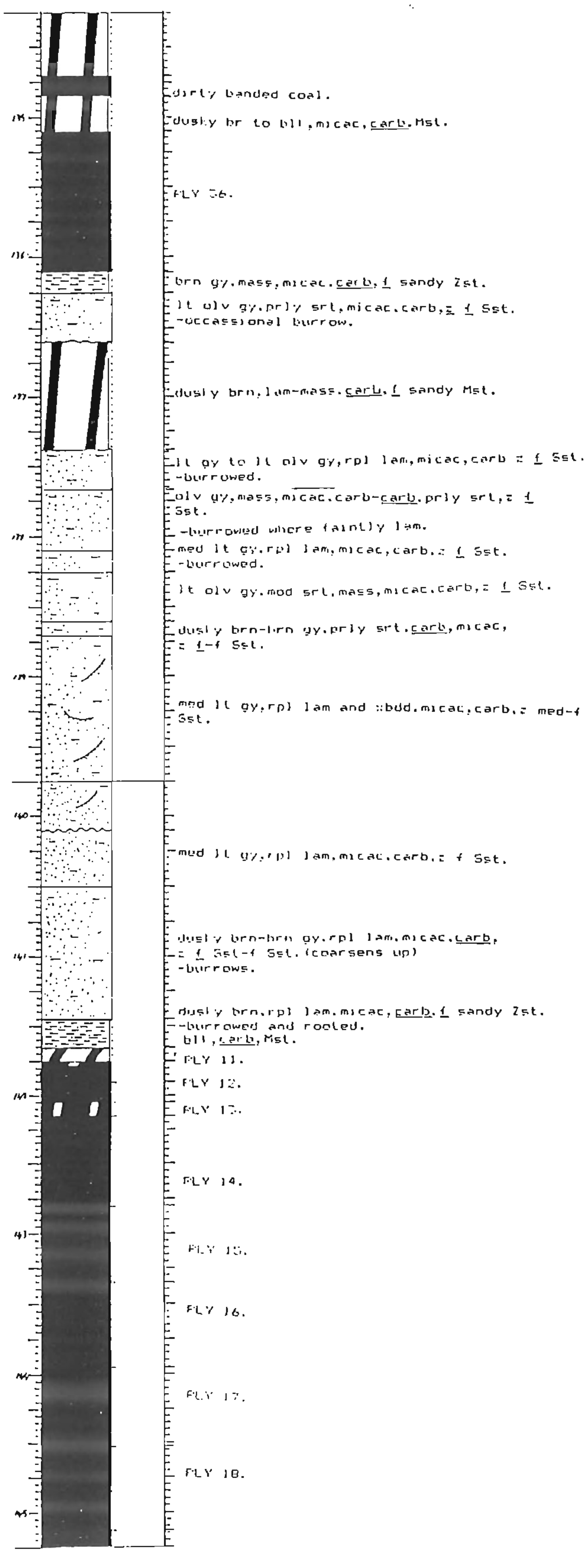
[illegible] to med lt gy,rpl lam,
[illegible] med [illegible]

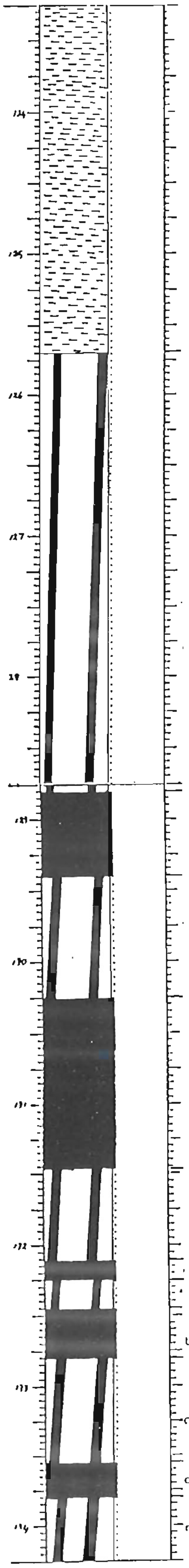
dusty brn,micac,carb,rpl lam,z f Sst.
-burrowed and rooted.
med lt gy,xbdd grading up into rpl lam,carb,
micac,z med-f to f Sst.

brn gy to med lt gy,rpl lam,micac,carb,
z f-med Sst.

dusty brn,prly srt,micac,carb,rpl lam to
faintly lam,z f Sst.
-burrowed and rooted.

lt gy,prly srt,micac,carb,xbdd,z med-crs to f
Sst.


dirty banded coal.
dusky br to bll,micac,carb.Mst.
FLY 36.
brn gy,mass,micac.carb,f sandy Zst.
lt olv gy,prly srt,micac.carb,z f Sst.
-occassional burrow.
dusly brn,lam-mass.carb,f sandy Mst.
lt gy to lt olv gy,rpl lam,micac,carb z f Sst.
-burrowed.
olv gy,mass,micac.carb-carb.prly srt,z f Sst.
-burrowed where faintly lam.
med lt gy,rpl lam,micac,carb,z f Sst.
-burrowed.
lt olv gy.mod srt,mass,micac.carb,z f Sst.
dusly brn-brn gy.prly srt.carb,micac,
z f-f Sst.
med lt gy,rpl lam and xbdd.micac,carb,z med-f Sst.
med lt gy,rpl lam,micac.carb,z f Sst.
dusly brn-brn gy.rpl lam,micac,carb,
z f Sst-f Sst.(coarsens up)
-burrows.
dusly brn,rpl lam,micac,carb,f sandy Zst.
-burrowed and rooted.
bll,carb,Mst.
FLY 11.
FLY 12.
FLY 13.
FLY 14.
FLY 15.
FLY 16.
FLY 17.
FLY 18.



brn gy to gy brn, faintly lam. micac, carb Mst.

PLY 38.

brn gy to brn bll., carb. Mst.

PLY 37.
- slightly siliceous at base.

dusky brn to bll, micac, carb, Mst.

bll, crushed, banded coal.

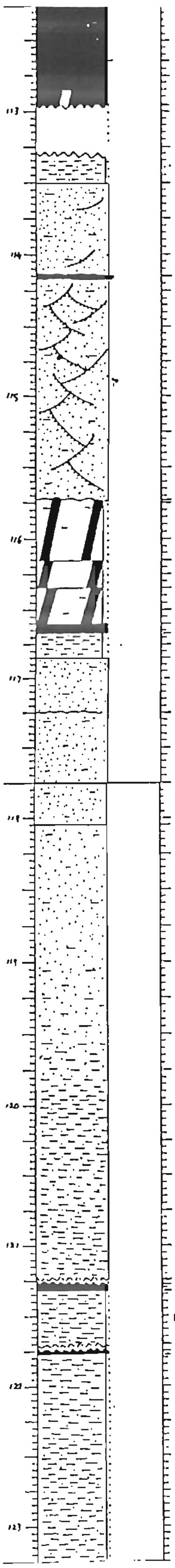
dusky brn to bll., carb. Mst.

bll, crushed, bright, banded coal.

dusky brn to bll, carb. Mst.

dirty to clean, banded coal.

dusky brn to bll, carb. Mst.



PLY 9

PLY 10

core loss(approx.30cm)

brn gy.rpl lam to mass,carb to carb.f sandy Zst.

lt olv gy.rpl and xbdd,micac,carb,mod-prly srt, z f to f Sst.

logs.

med lt gy.festoon xbdd,carb,micac,mod srt, z f-med gran Sst.

bll to brn bll.mass.carb.f sandy Zst and Mst.

bll,carb Mst/carbominerite.

blk to brn bll.mass to faintly lam.carb. f sandy Zst and carb.Mst/carbominerite.

bright coal.

brn gy to brn bll,rpl lam,micac,carb,f sandy Zst.

lt olv gy to brn gy,rpl lam,carb,micac,z f-f Sst.

brn gy to brn bll,rpl lam.carb,micac,z f-f Sst.
-rooted.

brn gy.s Zst to z f Sst.
-rooted.

minor core loss.

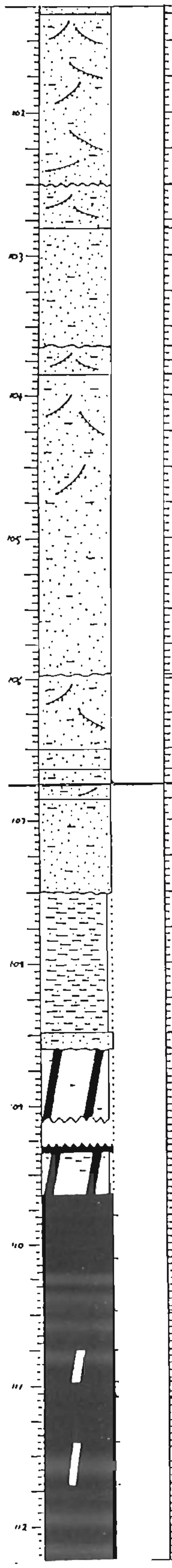
coal.

brn gy to lt brn gy,rpl lam,carb-carb,micac, f sandy Zst.

minor core loss.

coal.

brn gy,rpl lam,carb,micac,f sandy Zst.
-burrowed and rooted.



lt olv gy to lt gy.trgh-xbdd.prly srt,carb.z f-med Sst and med-crs Sst.
-pyr present.

lt olv gy.trgh-xbdd.carb to carb(towards top) z f-med Sst.
-pyr present.

lt gy.mass.prly srt,micac,z gran med-crs Sst.
-pyr present.

lt olv gy,trgh-xbdd,carb,micac, z f-med Sst.

lt gy.mass to trgh-x-bdd,prly-mod srt,micac. carb,z med-gran Sst.

lt olv gy to lt brn gy.xbdd,carb.z med-f Sst.

lt gy,mass.micac,z gran med-crs Sst.

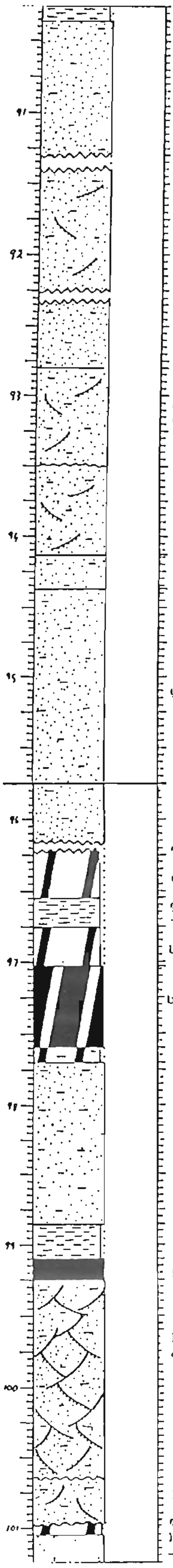
lt olv gy,xbdd,prly-mod srt.carb,z med-f Sst.

lt gy.mass.prly-mod srt,micac.z gran med-crs Sst.

bll to brn gy.finely lam,micaceous.carb,Mst, and f sandy Zst.
-burrowed and rooted.

lt olv gy,mass,carb,micac.z f Sst.

bll to brn gy.finely lam,micac.carb,Mst and s Zst.
core loss(approx.10-15cm)
core loss.
bll,thin coal.
bll to brn gy.finely lam to mass,micac,carb, Mst grading up into f sandy Zst.
PLY 1
PLY 2
PLY 3
PLY 4
PLY 5
PLY 6
PLY 7
PLY 8
-locally siliceous.



gy brn,rpl lam,carb,micac,z f Sst.
-burrowed and rooted.
-pyr present.

core loss(approx.10-15cm)

med lt gy,xbdd,micac,carb,z med-crs gran Sst.
-pyr present.

core loss.

gy br,rpl lam,carb,micac,z f Sst.
-burrowed and rooted.

med lt gy,xbdd,micac,carb,mod srt,z med-crs gran Sst.

lt gy,xbdd,mic,carb,z f Sst.

lt olv gy,prly srt,rpl lam, carb,micac,z f Sst.

gy brn,mod srt,rpl lam,carb,micac,z f Sst.

minor core loss.

dusky brn to bll,carb,Mst.

gy brn,faintly lam,micac,carb,f sandy Zst.
-burrowed,rooted.

blk,mass,carb,Mst.

bright to dull,dirty,banded coal.

dusky brn to brn blk,mass to faintly lam,carb,
micac,f sandy Zst grading up into carb Mst.

med lt gy,prly srt,micac,carb,mass to faintly
lam,z f Sst.
-rooted.

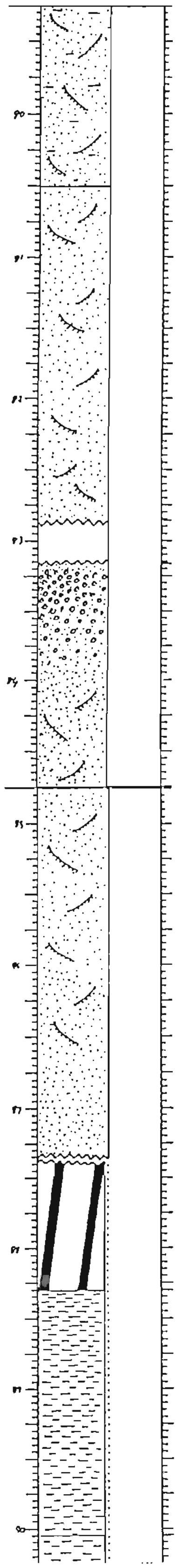
dusky brn,mass,carb,micac,f sandy Zst.

bll,bright to dull coal.

lt gy,festoon xbdd,micac,carb,z med to crs Sst,
coarsening up to gran Sst.
-pyr present.

lt gy to gy gn,xbdd,carb to carb,z f-crs Sst.

dusky brn to brn bll,micac,carb,Mst/carbominerite
lt olv gy to brn bll,rpl lam,carb,z f-f Sst.
-pyr present.



lt gy,xbdd,micac,carb,prly srt,z med-crs gran Sst.

lt gy,xbdd,micac,carb,f to med Sst.
-coarsening up into crs-gran Sst.

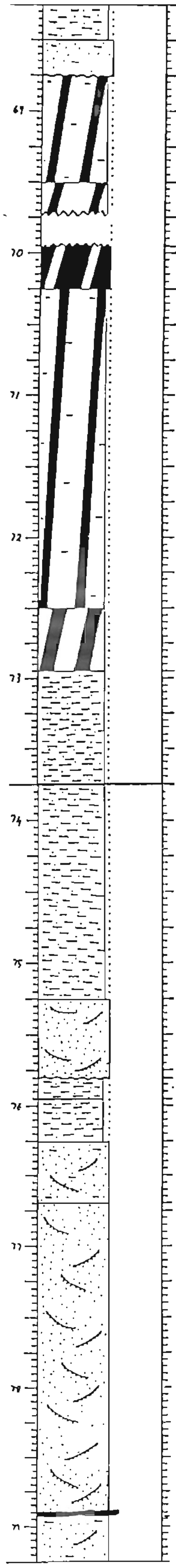
core loss.

lt gy,mass to xbdd,micac,prly srt,med-crs gran Sst.
-coarsening up into f pbl gran Sst.

dusky brn to brn blk,mass,carb,Mst and carbominerite.

lt olv gy,prly srt,mass to faintly lam,micac,carb,Zst.
-pyr present.

dusky brn,mass to faintly lam,carb Zst.



brn gy to dusty brn,lam,carb,micac,f sandy Zst.
-pyr present.

lt olv gy,rpl lam,carb,micac,mod well srt,
z f-f Sst.
-pyr present.

dusty brn,f lam,carb,s mZst-zMst.
-burrowed and rooted.

brn bll,faintly lam,carb,Mst.

core loss(approx.20cm)

blk,dirty coal.

dusky brn to gy brn,f lam,carb,s mZst-zMst.
-pyr present.

dusty brn,mass-f lam,micac,carb,f sandy Zst
and carbominerite.

lt olv gy,mass,prly srt,carb,micac,f
sandy Zst.

lt brn gy to lt gy,::bdd,carb,micac,mod srt,
z f Sst.

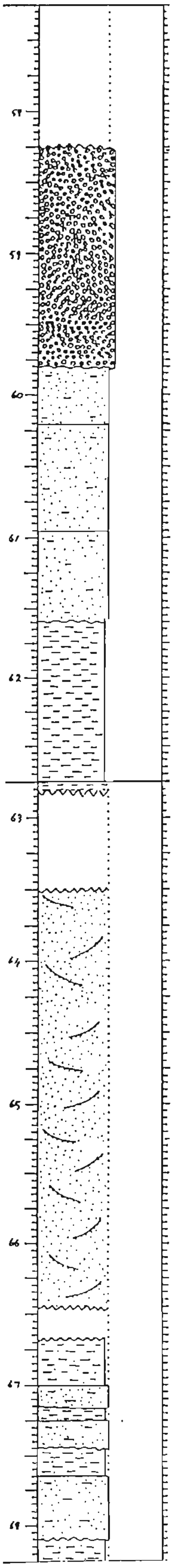
lt brn gy,faintly lam,carb,micac,f sandy Zst.

dusty brn,rpl lam,micac,carb,f sandy Zst.
-burrowed and rooted.

dusty brn to brn gy,::bdd and rpl,micac,carb to
carb,z f Sst.

lt gy,::bdd,micac,carb,f-med to crs Sst.

log



core loss(approx.1.60m)

lt gy to grn gy,mass.carb,micac,clast supported,
sandy(med-crs)f pbl cong.
-clasts of Greenland Group,qtz,and granite.

olv gy,rpl lam,micac,carb,z f Sst.
-burrowed.

lt olv gy,rpl lam,micac,carb,z f Sst.

lt gy to lt olv gy,prly srt,micac,carb,z gran-med
Sst.
-mass.

gy brn,mass to lam,micac,carb,f sandy Zst.
-burrowed.

core loss(approx.65cm)

lt gy,trgh-xbdd,carb,micac,pbl gran to med Sst.

core loss(approx.25cm)

brn gy to dusky brn,f lam.carb.f sandy Zst.

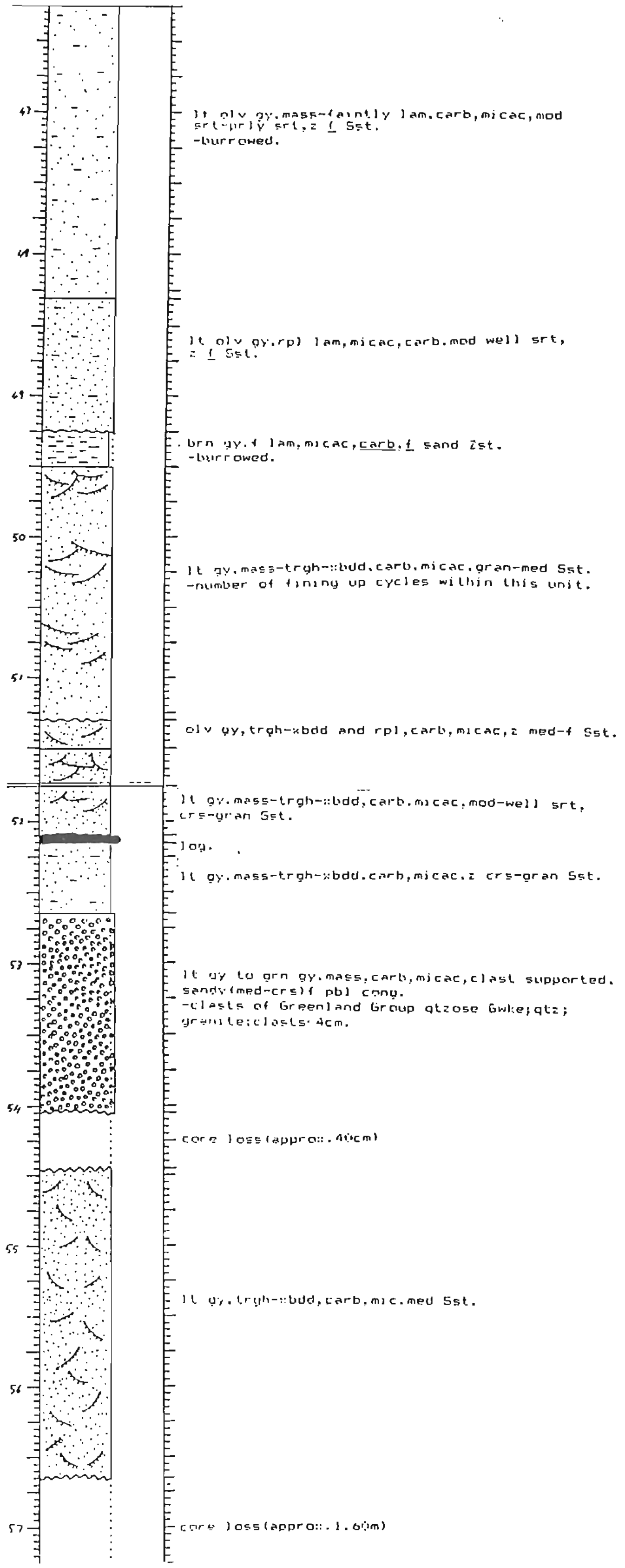
lt gy,rpl lam,micac,carb,prly srt,z f Sst.

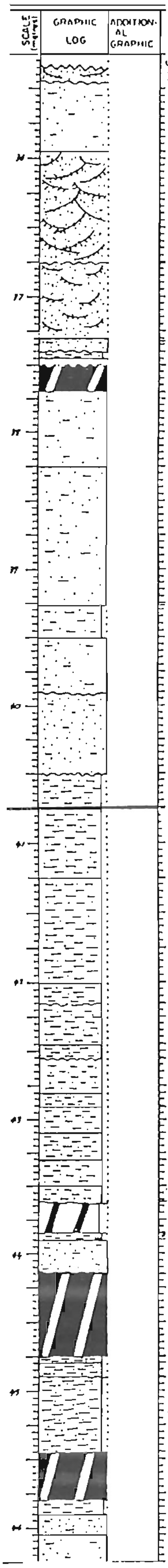
brn gy to dusky brn,f lam.carb,f sandy Zst.

lt gy,rpl lam,micac,carb,prly srt,z f Sst.

brn gy to dusky brn,f lam.carb.f sandy Zst.

lt olv gy,mass,micac-micac,prly srt,z f Sst.


lt olv gy.mass-faintly lam,carb,micac,mod srt-prly srt,z f Sst.
-burrowed.
lt olv gy.rpl lam,micac,carb.mod well srt, z f Sst.
brn gy.f lam,micac,carb,f sand Zst.
-burrowed.
lt gy.mass-trgh-xbdd.carb.micac.gran-med Sst.
-number of fining up cycles within this unit.
olv gy,trgh-xbdd and rpl,carb,micac,z med-f Sst.
lt gy.mass-trgh-xbdd,carb.micac,mod-well srt, crs-gran Sst.
log.
lt gy.mass-trgh-xbdd.carb,micac.z crs-gran Sst.
lt gy to grn gy.mass,carb,micac,clast supported. sandy(med-crs)f pbl cong.
-clasts of Greenland Group qtzose Gwke;qtz; granite:clasts 4cm.
core loss(approx.40cm)
lt gy.trgh-xbdd,carb,mic.med Sst.
core loss(approx.1.60m)



core loss.
lt gy.trgh-::bdd.z med Sst.

lt gy to olv gy.rpl lam.carb.mic.z f-f Sst.
-burrowed.

lt gy.festoon-::bdd,carb.micac.z crs Sst fining up into f Sst.(3 cycles)

lt gy,well srt,trgh-::bdd,carb.micac,z f-med Sst.

gy brn,rpl lam,carb,micac,f sandy Zst.
core loss.
bll.dirty,dull to british coal.

dk gy,rpl lam,micac,carb.z f-f Sst.

lt gy.rpl lam.micac,carb.z f-f Sst.

gy brn to dusky brn,rpl lam,carb,micac,f sandy Zst.
-burrowed.
lt gy,rpl lam,micac,carb.z f-f Sst.

lt gy to olv gy,rpl lam,micac,carb,z f-f Sst.

gy brn to dusky brn,rpl lam,carb,micac,f sandy Zst.
-burrowed.

gy brn to dusky brn,rpl lam,carb,micac,f sandy Zst.
-burrowed.

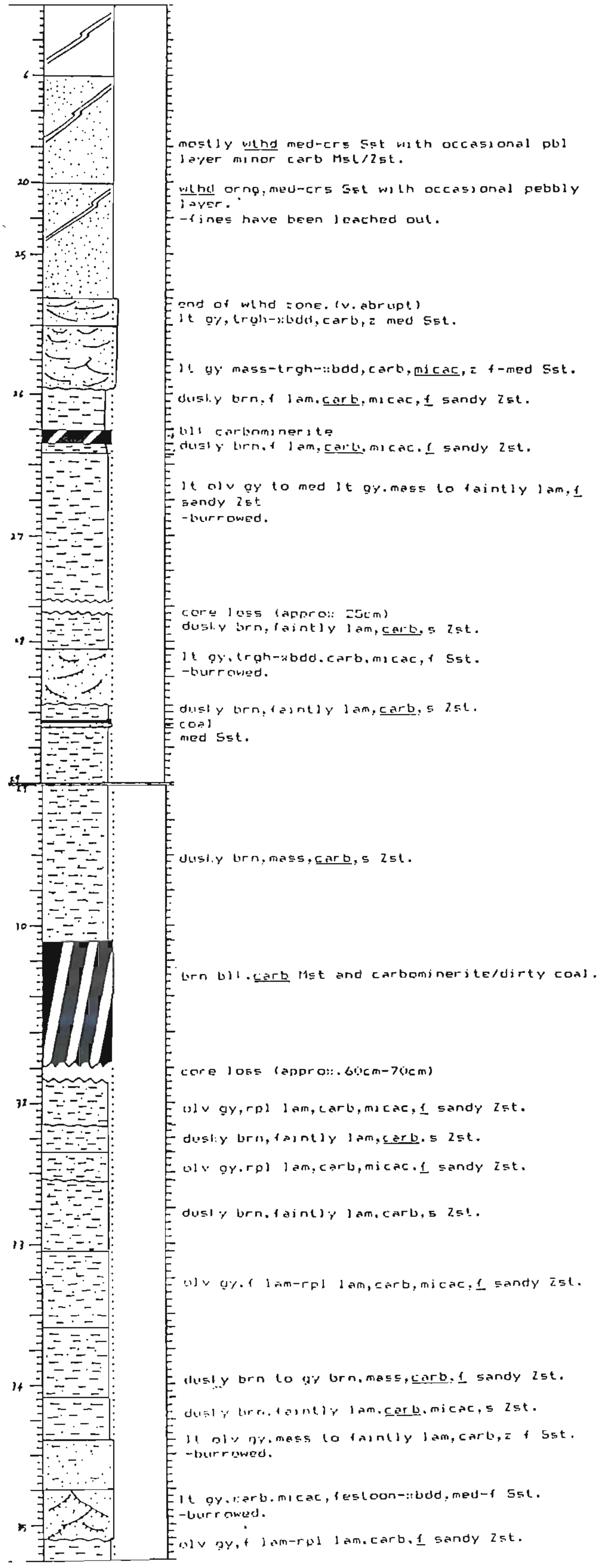
lt olv gy,rpl lam,carb.micac,f sandy Zst.
-burrowed.
gy brn to dusky brn,rpl lam,carb,micac,f sandy Zst.
-burrowed.
brn gy,rpl lam,carb.micac.f sandy Zst.
-burrowed.
gy brn to dusky brn,rpl lam.carb.mic.f sandy Zst.
-burrowed.
lt olv gy,rpl lam,carb.micac,f sandy Zst.
brn gy,rpl lam,carb,micac,f sandy Zst.
-burrowed.
gy brn,rpl lam,carb,micac,f sandy Zst.
-burrowed.
bll,faintly lam to lam,micac,carb z Mst.
-burrowed in places.
dusky brn,lam to mass,mic.carb s Zst.
lt olv gy.mass to f lam,prly srt,carb.micac, z f Sst.

bll,dirty coal and carbominerite.

gy brn.carb.micac,f sandy Zst.
lt olv gy to gy brn,rpl lam,carb.micac, f sandy Zst-z Sst.
brn gy to dusky brn,rpl lam,carb.f sandy Zst.
-burrowed.

bll,dirty dull coal.

dusky brn,f lam,carb,f sandy Zst.
-burrowed.
lt olv gy.rpl lam,micac.carb-carb,z f Sst.
-burrowed.


mostly wthd med-crs Sst with occasional pbl layer minor carb Mst/Zst.
wthd orng,med-crs Sst with occasional pebbly layer.
-fines have been leached out.
end of wthd zone.(v.abrupt)
lt gy,trgh-xbdd,carb,z med Sst.
lt gy mass-trgh-xbdd,carb,micac,z f-med Sst.
dusky brn,f lam,carb,micac,f sandy Zst.
bll carbominerite
dusky brn,f lam,carb,micac,f sandy Zst.
lt olv gy to med lt gy.mass to faintly lam,f sandy Zst
-burrowed.
core loss (approx 25cm)
dusky brn,faintly lam,carb,s Zst.
lt gy,trgh-xbdd.carb,micac,f Sst.
-burrowed.
dusky brn,faintly lam,carb,s Zst.
coal
med Sst.
dusky brn,mass,carb,s Zst.
brn bll.carb Mst and carbominerite/dirty coal.
core loss (approx.60cm-70cm)
olv gy,rpl lam,carb,micac,f sandy Zst.
dusky brn,faintly lam,carb.s Zst.
olv gy.rpl lam,carb,micac.f sandy Zst.
dusky brn,faintly lam,carb,s Zst.
olv gy.f lam-rpl lam,carb,micac,f sandy Zst.
dusky brn to gy brn,mass,carb.f sandy Zst.
dusky brn.faintly lam,carb,micac,s Zst.
lt olv gy,mass to faintly lam,carb,z f Sst.
-burrowed.
lt gy.carb.micac,festoon-xbdd,med-f Sst.
-burrowed.
olv gy,f lam-rpl lam.carb.f sandy Zst.

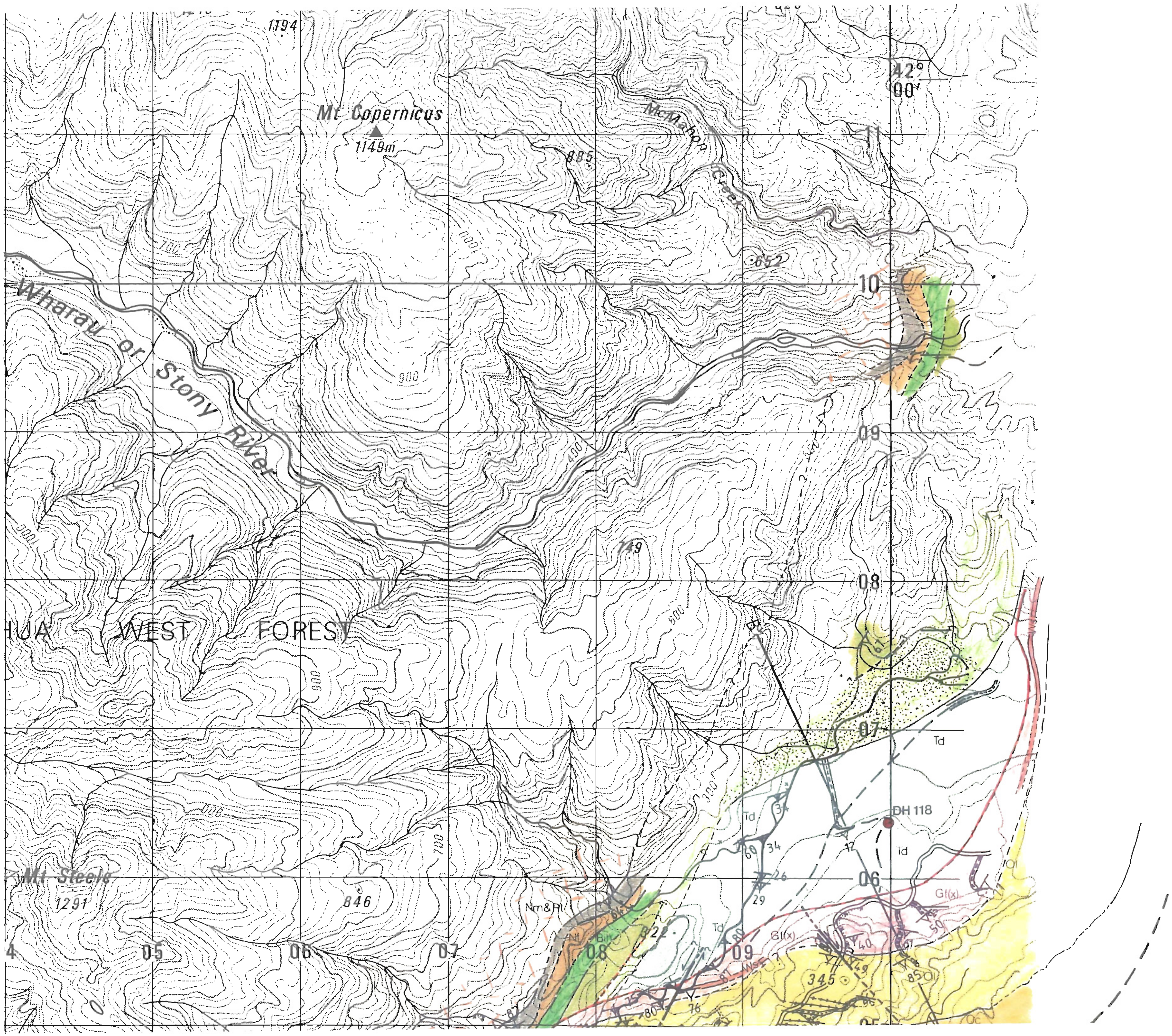
APPENDIX 13

SCANNING ELECTRON MICROSCOPE SAMPLE PREPARATION

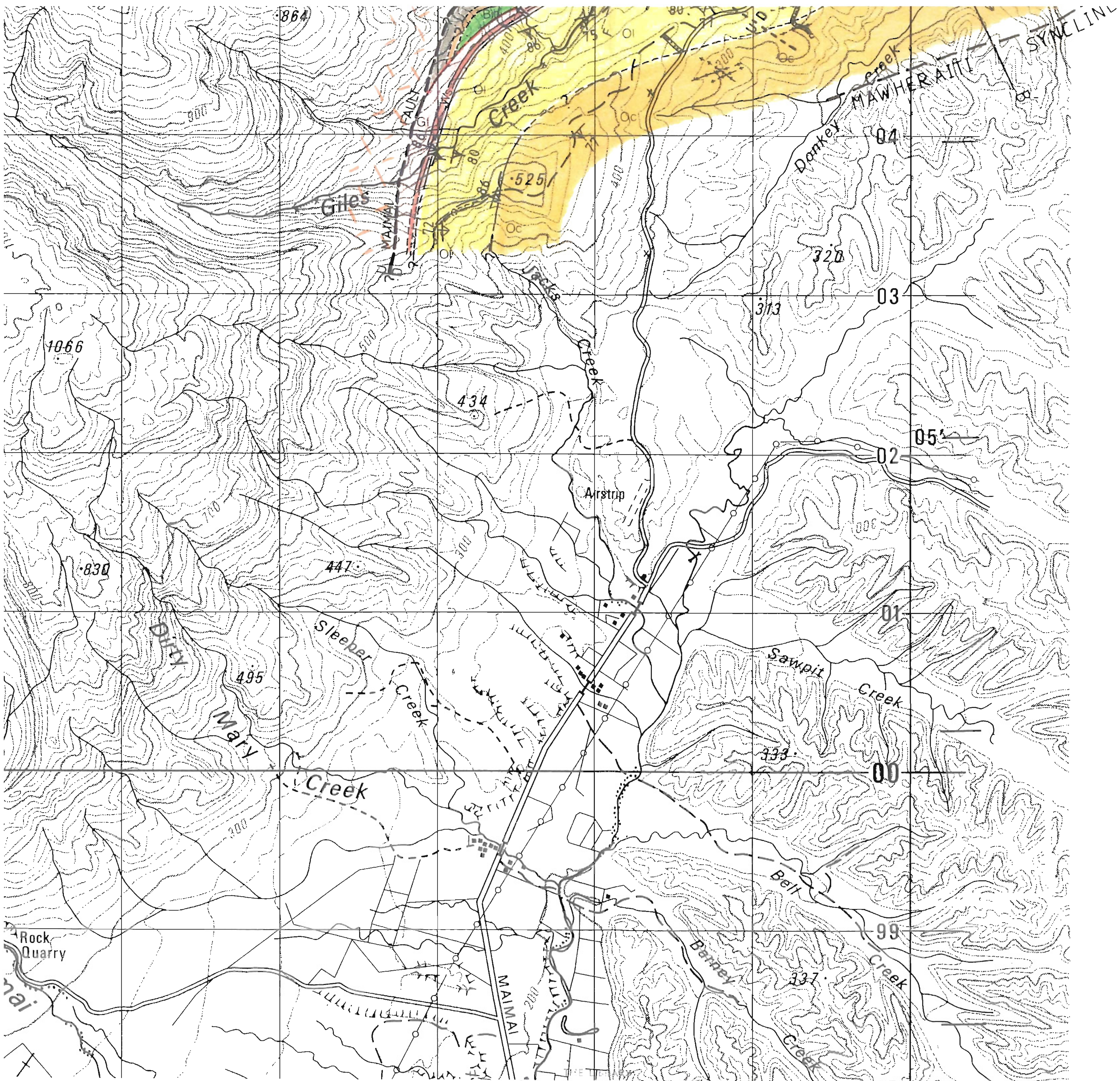
Small blocks of silicified coal were mounted in Lucite thermoplastic resin and polished using the techniques described previously in Appendix 4. Samples were prepared by Mr K. Swanson of the University of Canterbury Geology Department by firstly being cleaned in an ultrasonic bath with alcohol, to remove residual polish, grease, and water.

The samples were then air dried using compressed air, and oxidised within a $HNO_3 + KClO_3$ mixture for about 10 minutes (samples were checked every minute by washing with distilled water, drying and examining under a binocular microscope), until sufficient relief was present for SEM examination. The rate of oxidation was dependent on the organic composition.

Finally the samples were mounted on a stub using "super glue", with the perimeter of the resin block dabbed with silver or graphite, and then the samples were coated in gold using a sputter coater for 4 minutes.

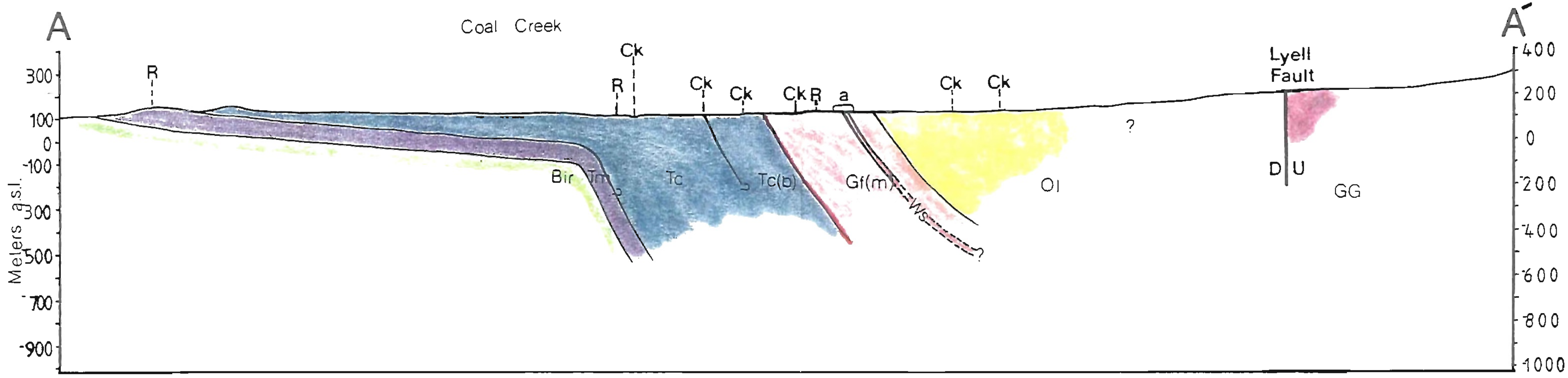


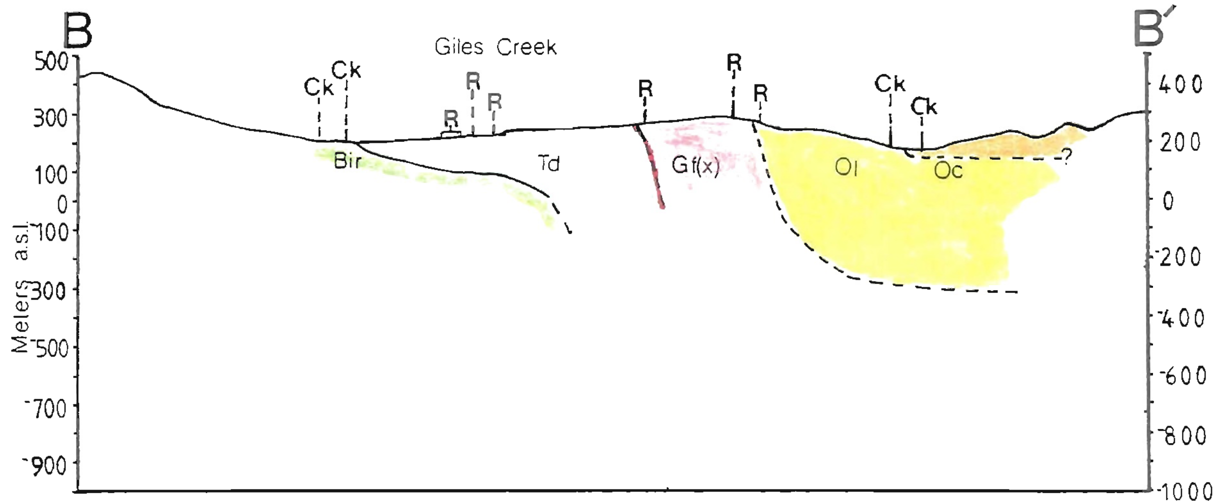
Mt Copernicus
1149m
1194
McMahon Creek
885
652
42°
00′
10
09
08
07
06
Wharau or Stony River
900
700
1000
400
749
600
500
300
HUA WEST FOREST
Td
DH 118
Nm&Ri
Gf(x)
Mt Steele
1291
846
345
05
06
07
08
09



864
Giles
MAIMAI
FAULT
Creek
525
Oc
Ol
Gl
Donkey Creek
MAWHERAITI
SYNCLINE
04
320
03
313
Jacks Creek
1066
434
05
02
Airstrip
447
830
01
Dirty Mary Creek
Sleeper Creek
495
Sawpit Creek
333
00
Belt Creek
99
Rock Quarry
Barney Creek
337
MAIMAI

CROSS SECTIONS

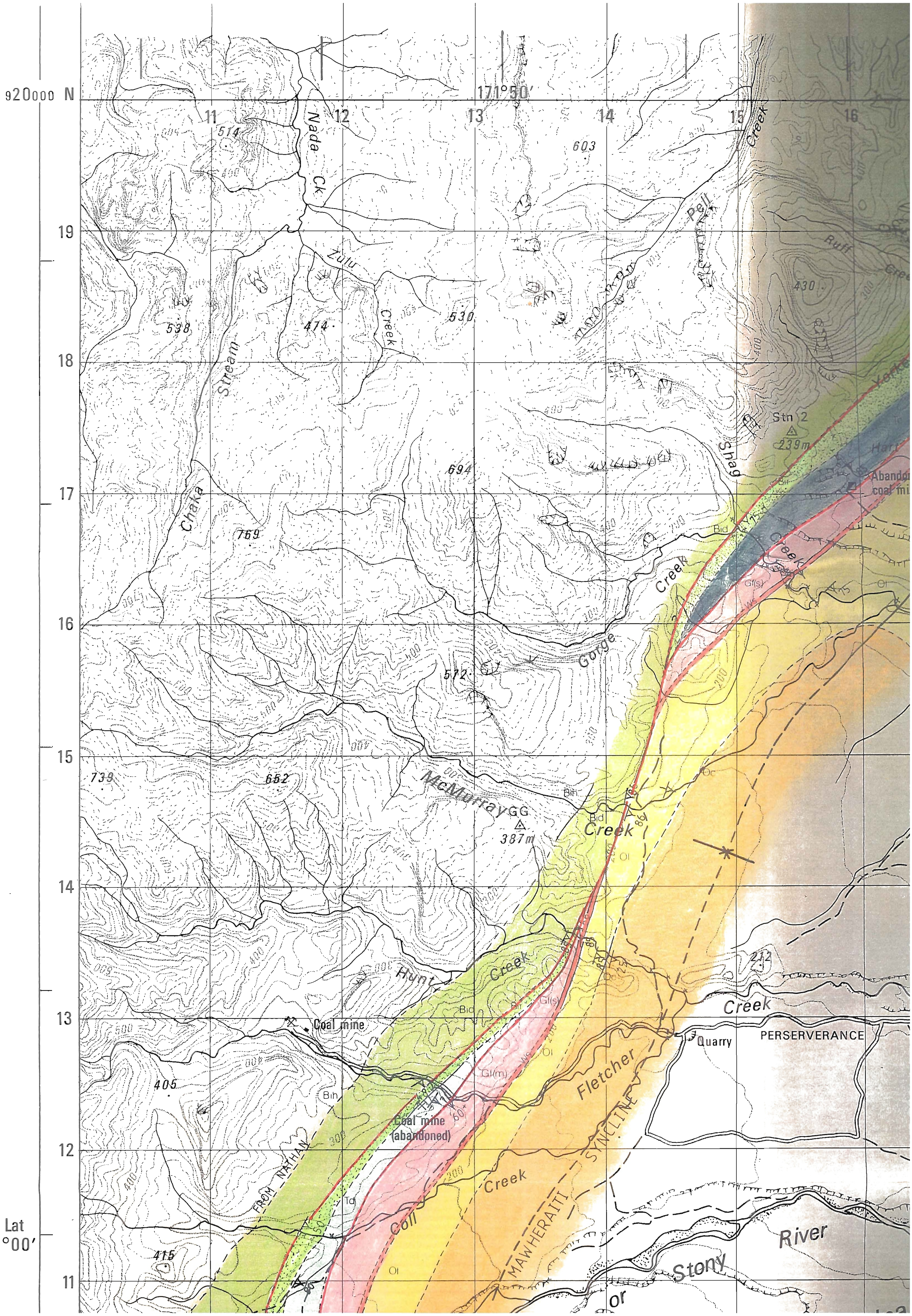




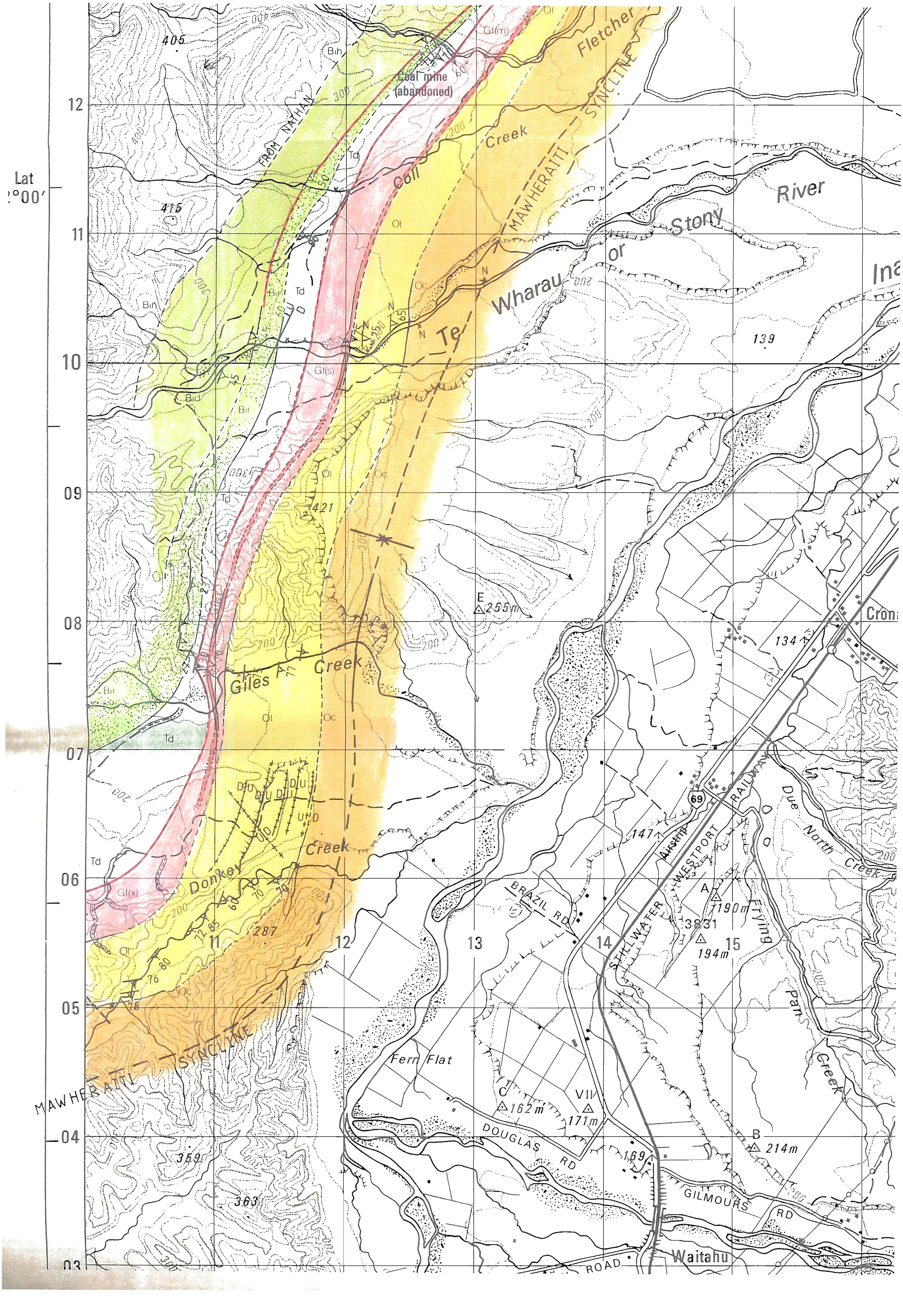
R= river
Ck=creek
a= airstrip

Meters
0 1000

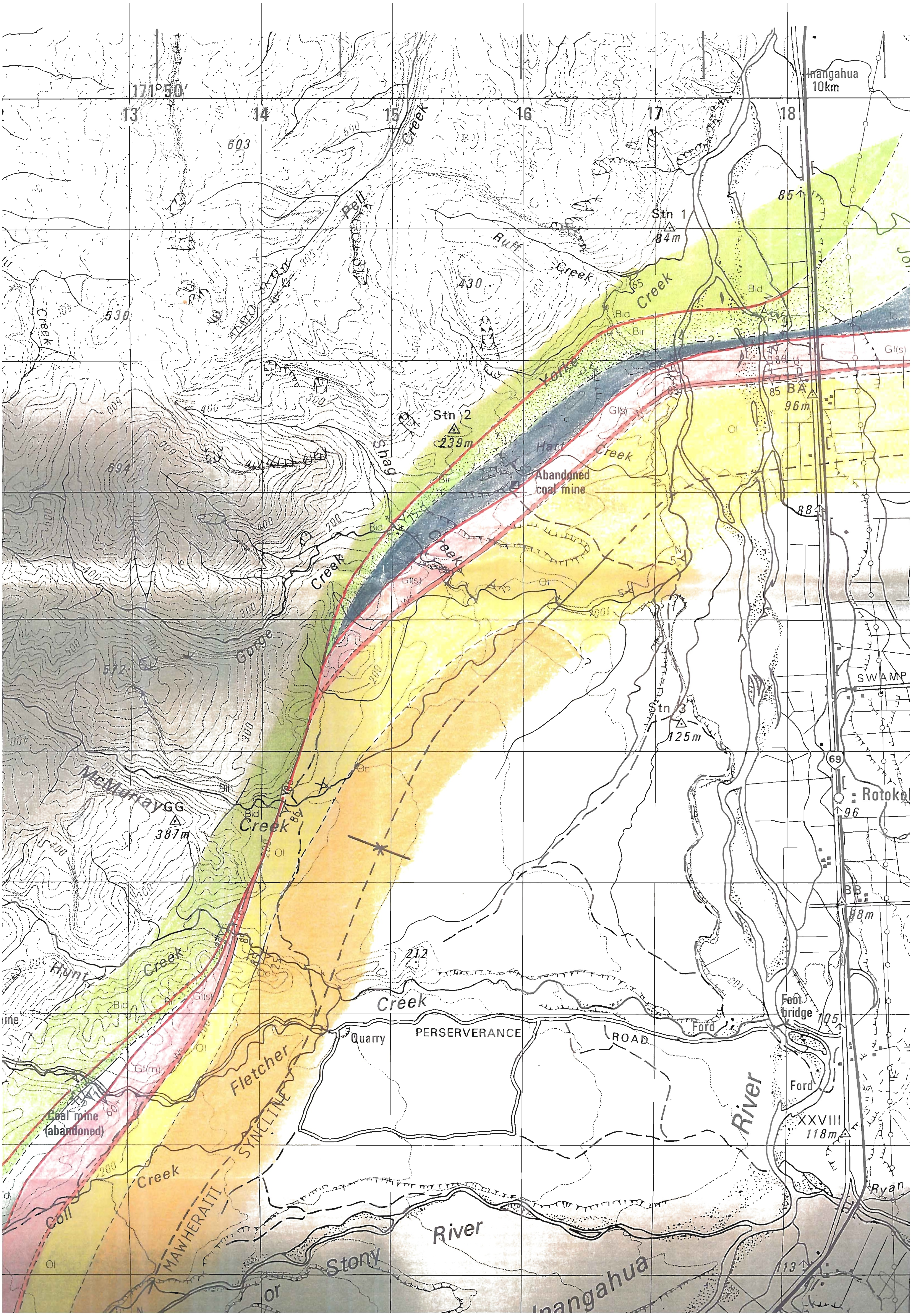
Scale 1:25000 VE=0



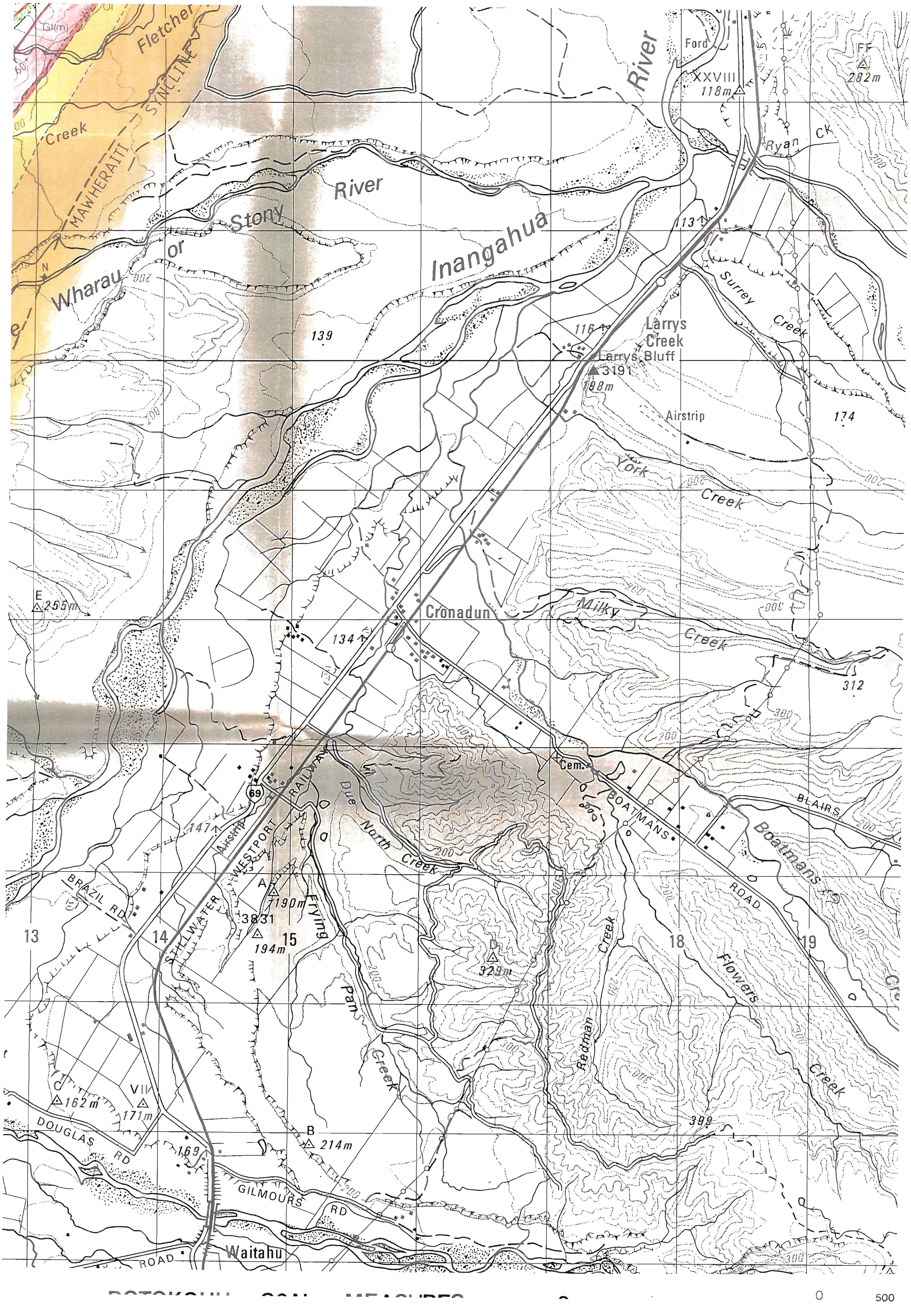
920000 N
171°50′
11
12
13
14
15
16
19
18
17
16
15
14
13
12
11
Lat
°00′
Nada Ck
Zulu Creek
Chaka Stream
Pell Creek
Shag Creek
Ruff Creek
Gorge Creek
McMurray Creek
Hunt Creek
Fletcher Creek
Coll Creek
Stony River
Creek
Stn 2
239m
GG
387m
Coal mine
Coal mine (abandoned)
Abandon coal mi
Quarry
PERSERVERANCE
FROM NATHAN
MAWHERAITI SYNCLINE
514
603
538
474
530
430
694
769
572
739
652
405
415
212
Bid
Bih
Bif
Gl(s)
Gl(m)
Ol
Oc
Tq



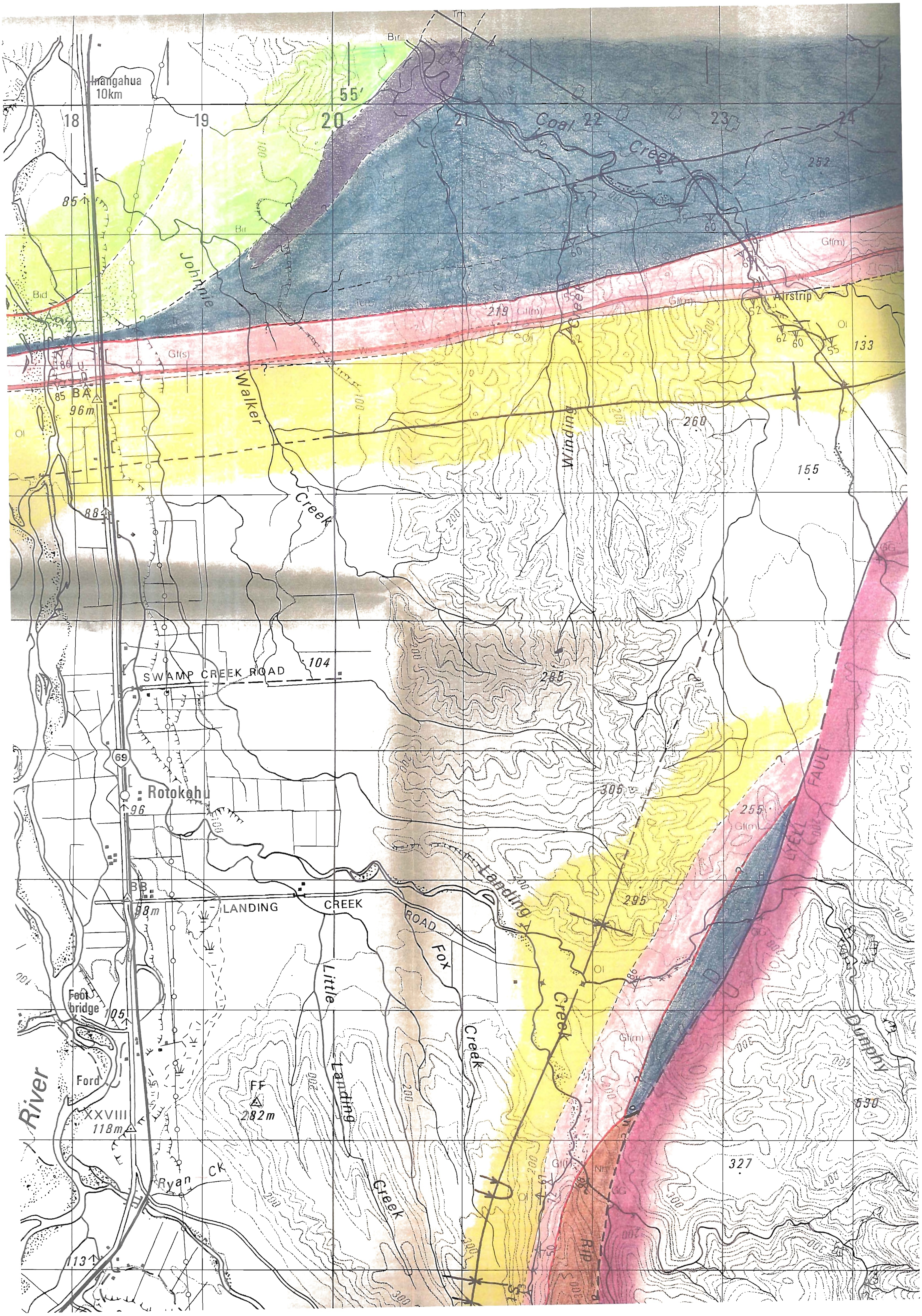
Lat
2°00′
12
11
10
09
08
07
06
05
04
03
11
12
13
14
15
Coal mine
(abandoned)
FROM NATHAN
Fletcher
Creek
MAWHERAITI SYNCLINE
Coal
Creek
River
Stony
or
Wharau
Te
Ina
Giles Creek
Donkey Creek
MAWHERAITI SYNCLINE
E
255m
139
134
Crona
147
69
WESTPORT
RAILWAY
Airstrip
STILLWATER
BRAZIL RD
Due North Creek
Frying
Pan
Creek
A
190m
3831
194m
Fern Flat
C
162m
VII
171m
DOUGLAS RD
169
B
214m
GILMOURS RD
ROAD
Waitahu
405
415
421
287
359
363
Bih
Bit
Bid
Td
Gt(m)
Gt(s)
Gt(x)
Ot
Oc
Ws



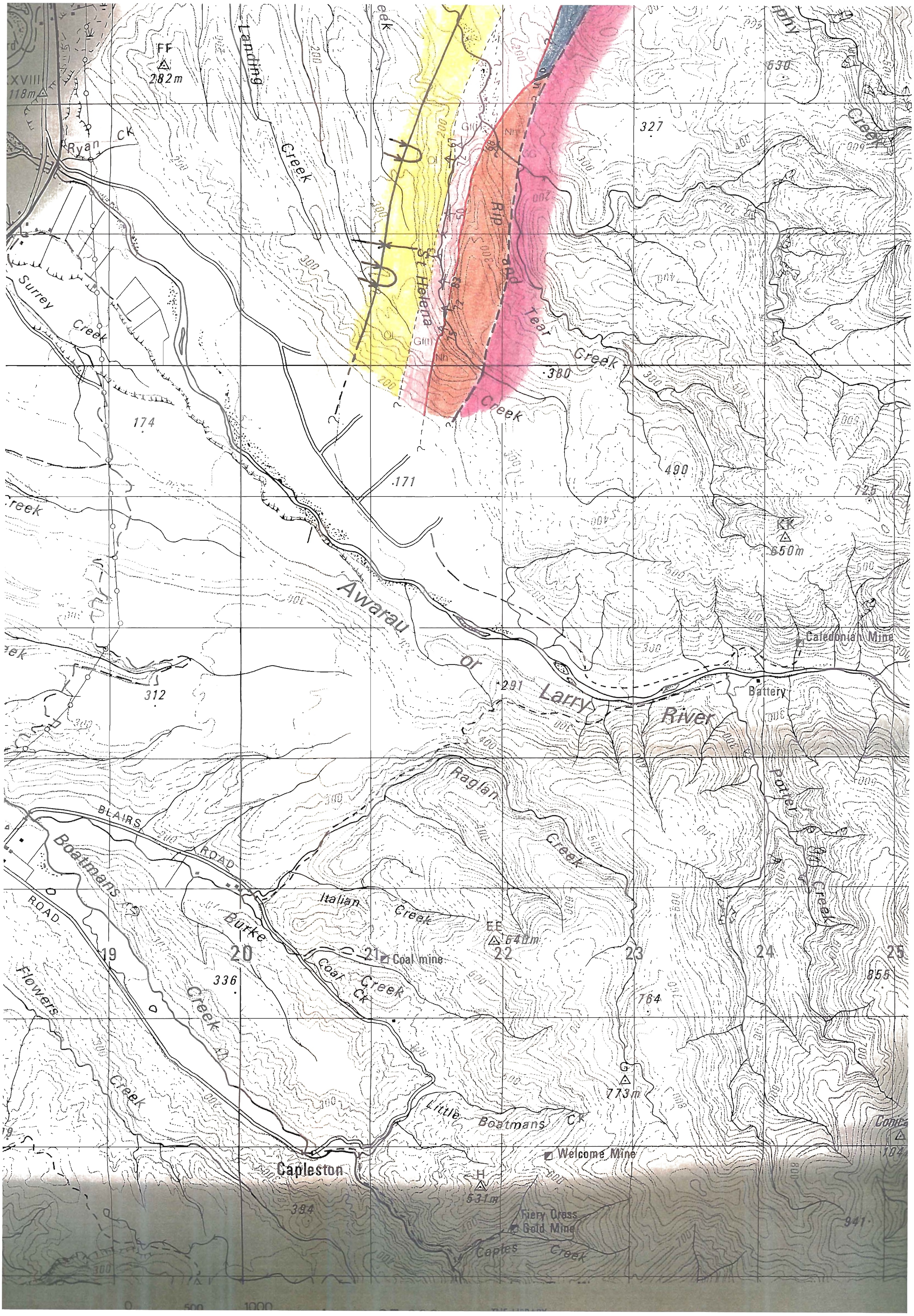
171°50′
13
14
15
16
17
18
Inangahua
10km
Pell
Creek
Ruff
Creek
Stn 1
84m
603
530
430
Yorke
Creek
Stn 2
239m
Shag
Harr
Creek
Abandoned
coal mine
694
Gorge
Creek
572
McMurray
GG
387m
Creek
Bld
Bir
Gl(s)
Ol
Tc
Oc
Gl(m)
BA
96m
85
88
Stn 3
125m
SWAMP
69
96
BB
98m
212
Hunt
Creek
Creek
Quarry
PERSERVERANCE
ROAD
Ford
Foot
bridge
105
River
Ford
XXVIII
118m
Fletcher
MAWHERAITI SYNCLINE
Coal mine
(abandoned)
Creek
Coll
River
Stony
Inangahua
Ryan



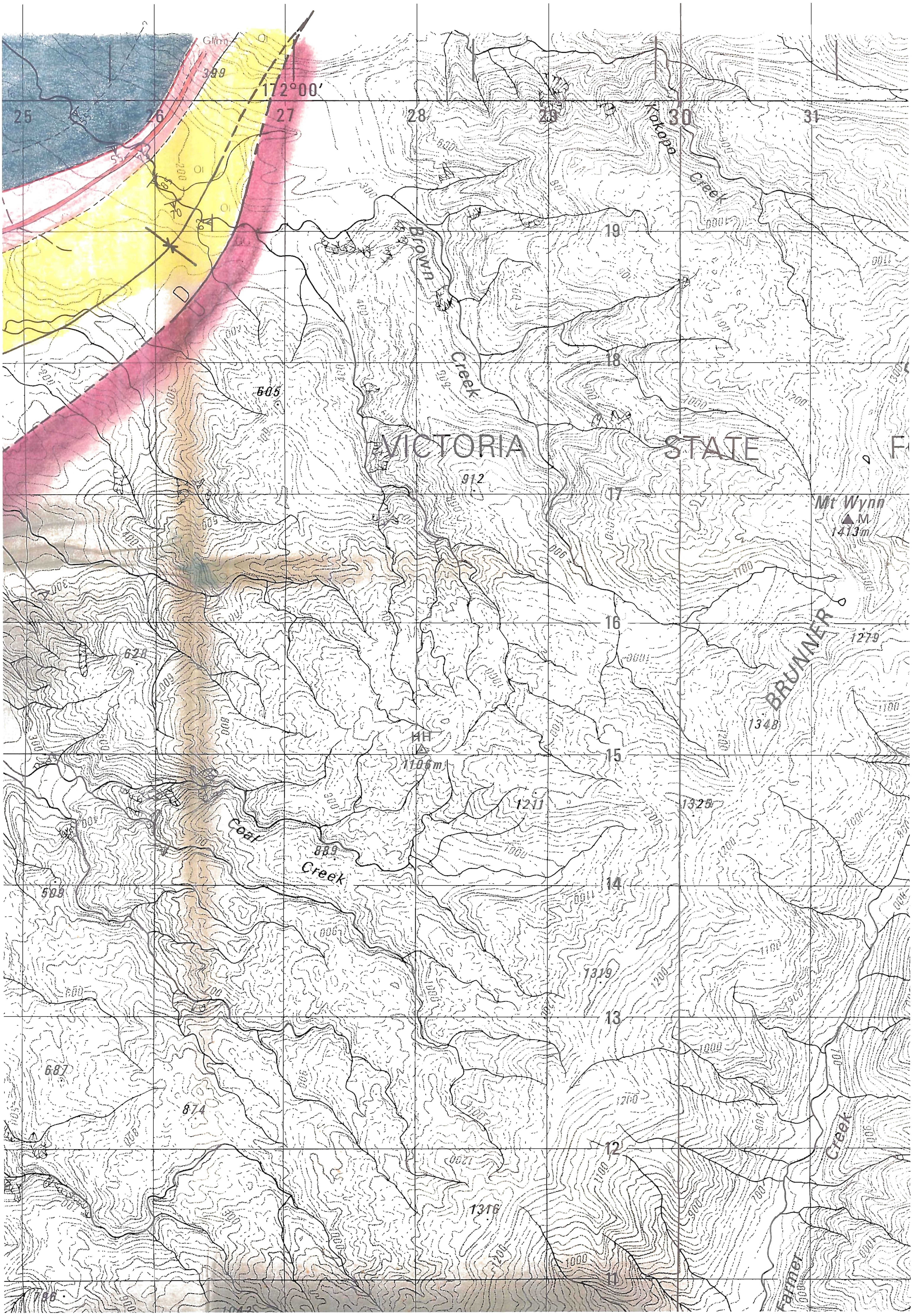
Fletcher
MAWHERAITI SYNCLINE
Creek
Wharau or Stony River
Inangahua River
Ford
XXVIII
118m
FF
282m
Ryan Ck
113
Surrey Creek
116
Larrys Creek
Larrys Bluff
3191
198m
Airstrip
174
139
York Creek
Milky Creek
Cronadun
134
312
E
255m
Cem.
69
RAILWAY
WESTPORT
STILLWATER
Airstrip
147
BRAZIL RD
Due North Creek
Frying Pan Creek
BOATMANS ROAD
Boatmans Ck
BLAIRS
A
190m
3831
194m
D
329m
Redman Creek
Flowers Creek
13
14
15
18
19
C
162m
VII
171m
DOUGLAS RD
169
B
214m
GILMOURS RD
399
ROAD
Waitahu
0
500

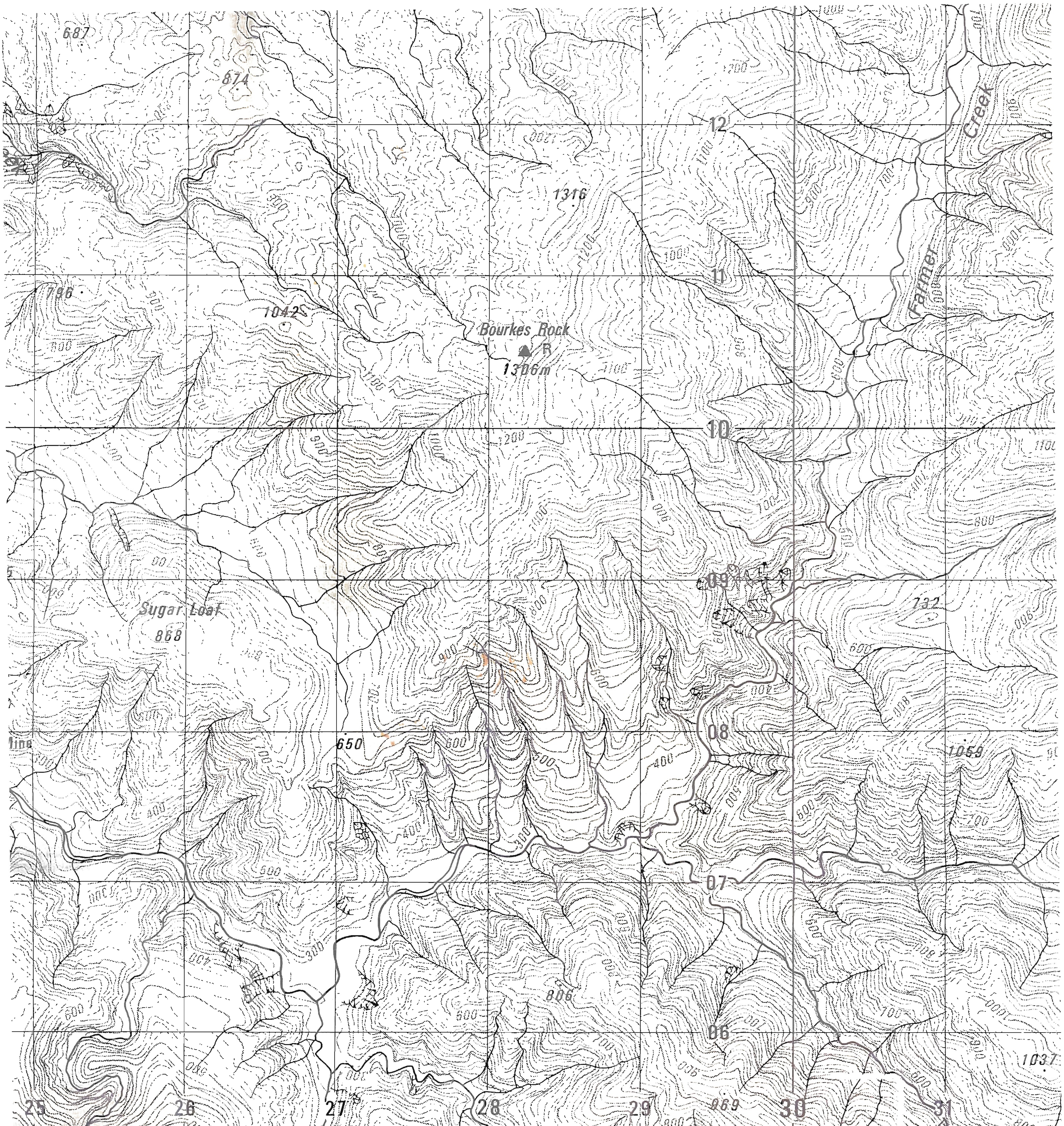


Inangahua
10km
18
19
20
55′
21
22
23
24
Coal
Creek
252
Airstrip
133
Johnnie
Walker
Creek
219
Winding
Creek
BA
96m
260
155
SWAMP CREEK ROAD
104
285
69
Rotokohu
96
305
255
LYELL FAULT
BB
98m
LANDING
CREEK
ROAD
Landing
Fox
Little
Landing
Creek
295
Foot
bridge
105
River
Ford
FF
282m
XXVIII
118m
Dunphy
630
327
Ryan CK
Rip
113



FF
282m
118m
Ryan Ck
Landing
Creek
Surrey
Creek
St Helena
Rip and Tear Creek
327
380
174
171
490
KK
650m
Awarau or Larry River
Caledonian Mine
Battery
291
312
Raglan Creek
Potter
Creek
BLAIRS ROAD
Boatmans
Italian Creek
EE
640m
Burke
Coal mine
Coal Ck
Coal Creek
19
20
21
22
23
24
25
336
764
855
ROAD
Flowers Creek
Creek
G
773m
Little Boatmans Ck
Welcome Mine
Capleston
H
531m
394
Fiery Cross Gold Mine
Caples Creek
941


172°00′
25
26
27
28
29
30
31
Kokopo Creek
Brown Creek
19
18
17
16
15
14
13
12
11
605
VICTORIA STATE FO
912
Mt Wynn
1413m
BRUNNER
1279
628
1348
HH
1106m
1211
1328
Coal Creek
889
509
1319
687
874
1316
Creek
Farmer
786



Bourkes Rock
1306m
1316
1042
Sugar Loaf
868
Farmer
Creek
732
1059
650
806
1037
628
887
1073
Conical Hill
1047m
Drysdale
Silcock
1244m
12
11
10
09
08
07
06
05
04
25
26
27
28
29
30
31

MAP LEGEND

STRIKE AND DIP	SYMBOLS			
	DIP			
	Horizontal	Not Overturned	Vertical	Overturned
Face defined at outcrop		5		5
Face inferred from field relationships		5		5
Undulating bedding	5			
Exhumed erosion surface				
FOLDS	Not Overturned		Overturned	
Upfold anticline and /or antiform				
Downfold syncline and/ or synform				
Monoclinal hinge				
Forestry road, plotted from aerial photographs				

CONTACTS	SYMBOLS	
Contact, observed		
Contact (inferred from structure contours)		
FAULTS		
Fault, showing dip	60	
Fault	Major	Minor
	U D	U D
from aerial photographs		
Late Quaternary fault trace	1968	
Small fault observed in field	F	

KEY

BASEMENT

- Granite
- GG Greenland Group

INANGAHUA FORMATION

- Bir Ram Creek Member ★
- Bid De Filippi Mudstone ★
- Bih Hunt Member ★

LOWER TERTIARY UNITS

- Nf Fletcher Limestone ★
- Nh Whitecliffs Formation ★
- Nm & Rl Te Wharau Sand and McMurray Limestone ★

GILES FORMATION

defined in Text
- Ws Winding Shelly Sandstone
- Gl Giles Fm (undifferentiated)

ROTOKOHU COAL MEASURES

defined in Text
- Tc Camp Member
- Tm Thomson Member
- Td Donkey Member

OLD MAN GROUP

- Oc Cronadun Conglomerate ★
- Ol Larry Schist Conglomerate ★

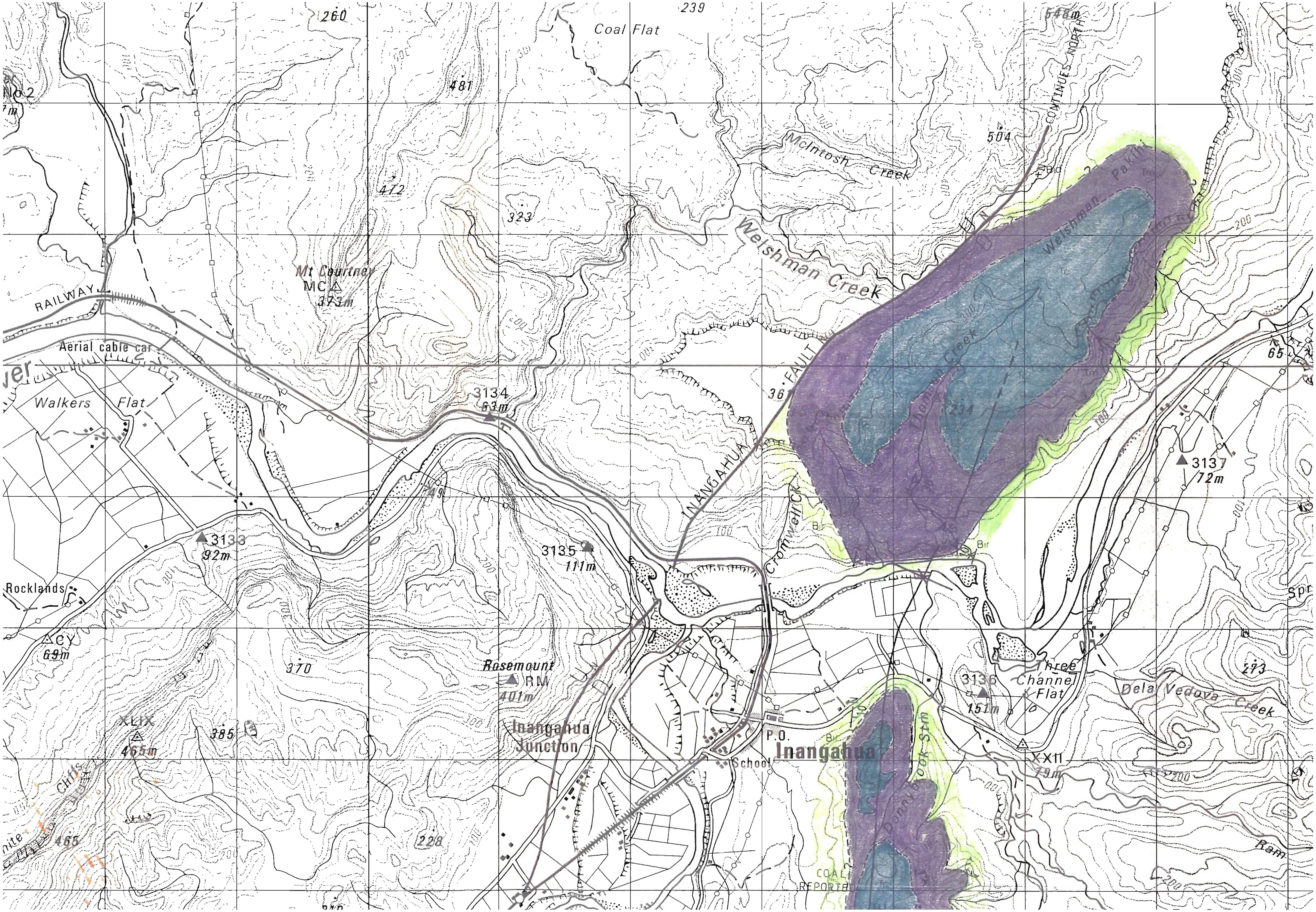
★ defined by Nathan (1974)

Unconformity

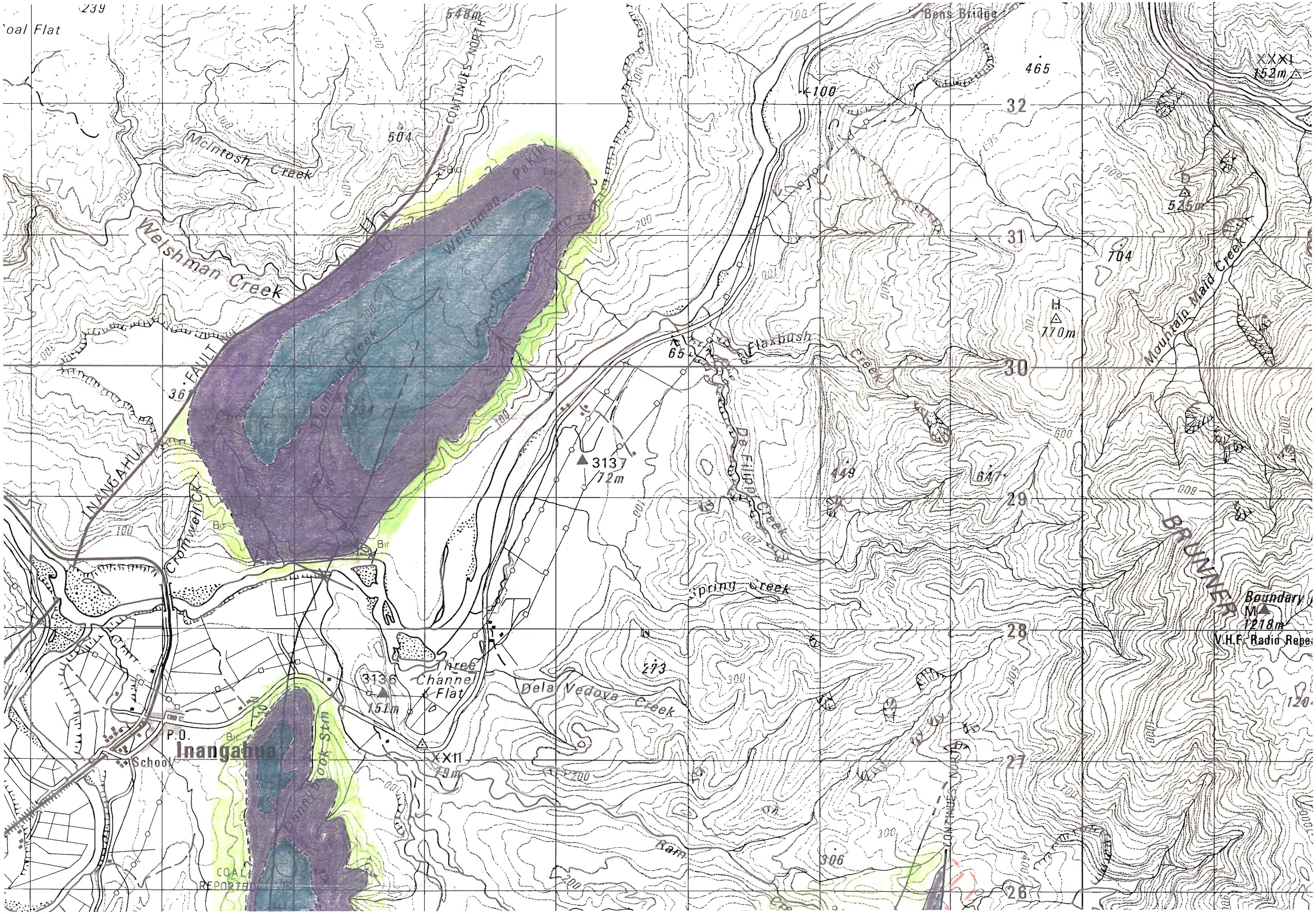
Ni Iron Bridge ★ Lst.

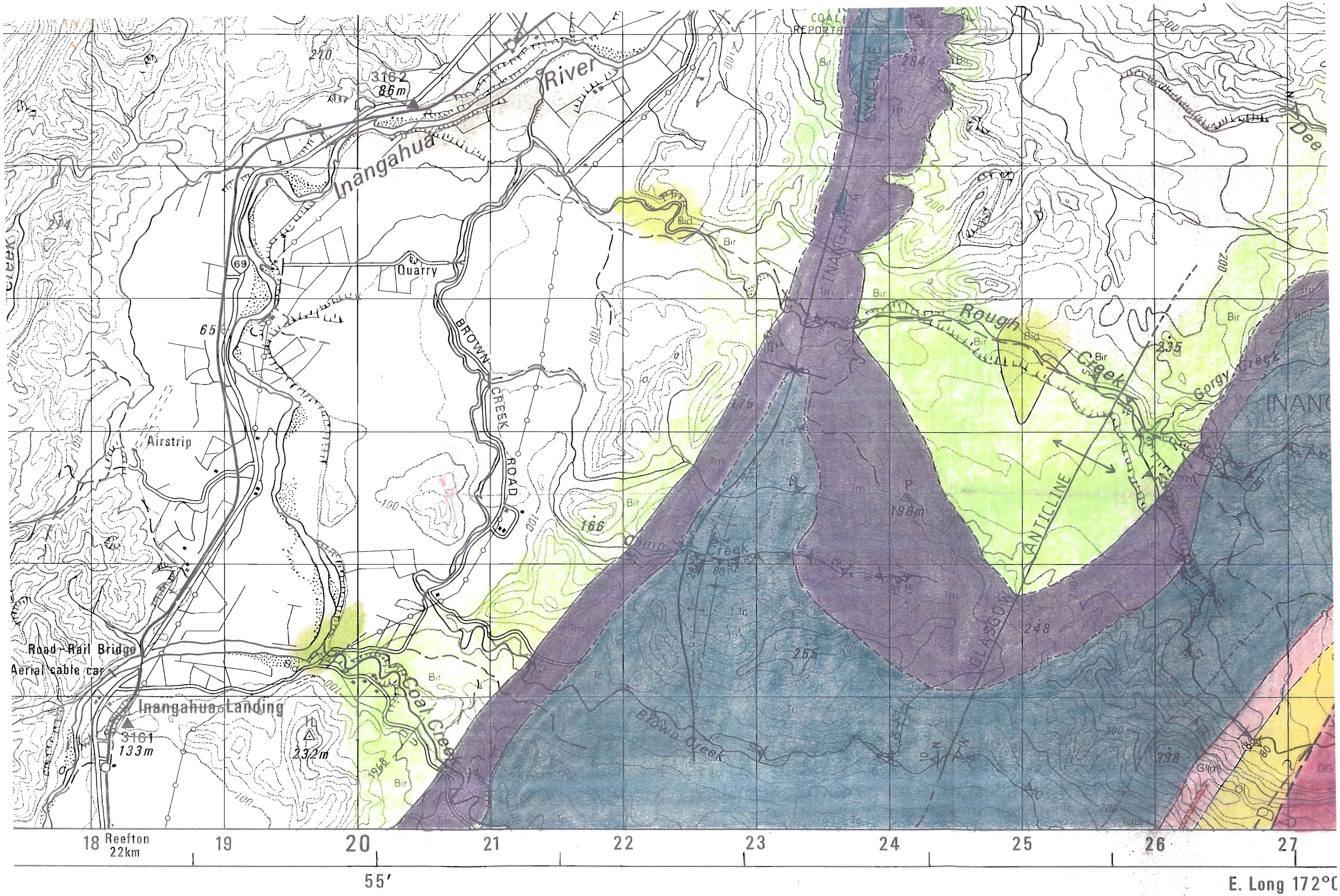
DH 118

N from Nathan 1978a
S Suggate 1957
W Wellman 1950
H Henderson 1917

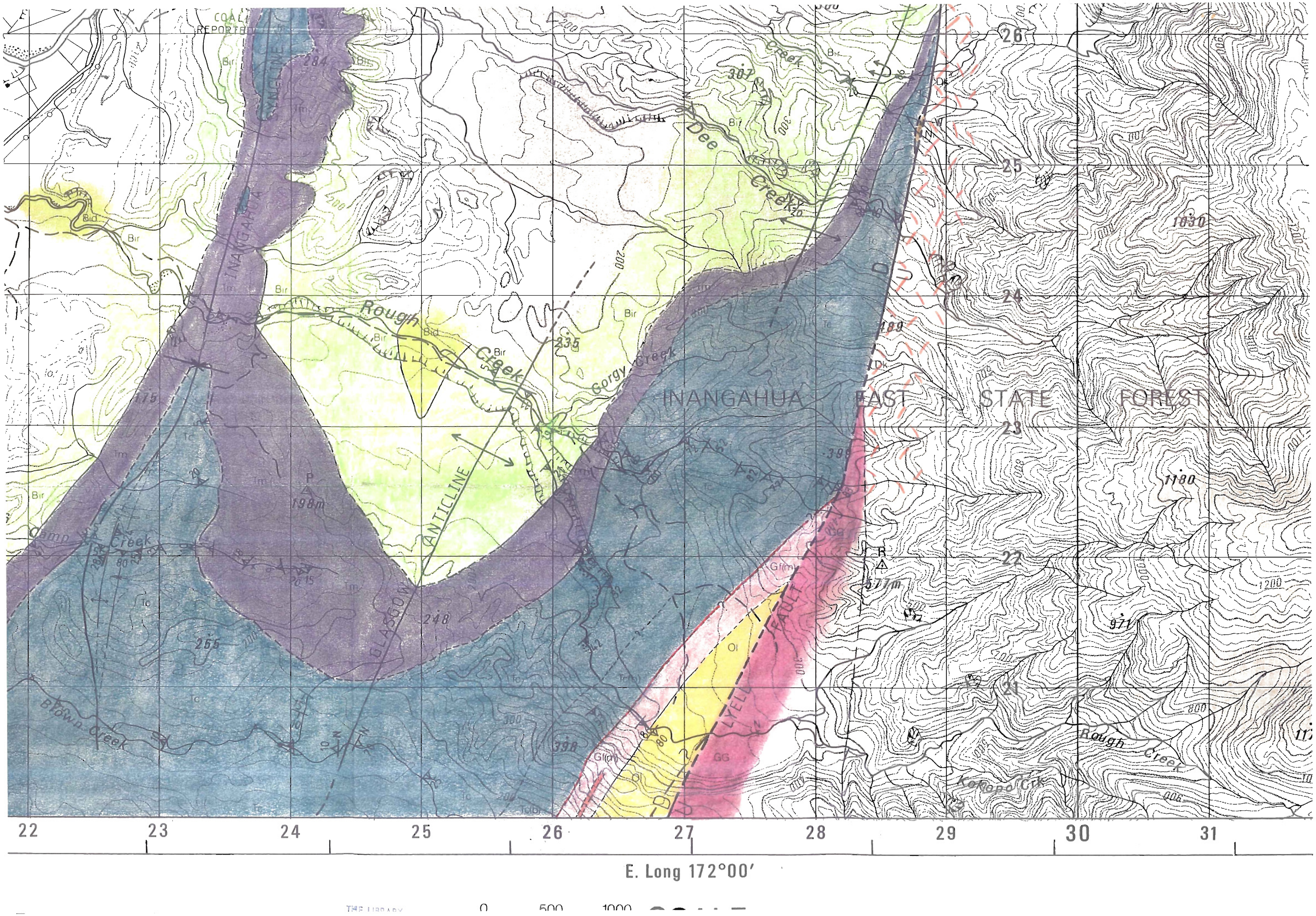


Coal Flat
239
260
481
504
548m
CONTINUES NORTH
McIntosh Creek
Welshman Creek
Welshman
Pakihi
472
323
Mt Courtney
MC
373m
RAILWAY
Aerial cable car
Walkers Flat
3134
63m
361
INANGAHUA FAULT
Thompson Creek
234
65
3137
72m
3133
92m
3135
111m
Cromwell Ck
Rocklands
CY
69m
370
Rosemount
RM
401m
XLIX
465m
385
Inangahua Junction
P.O.
Inangahua
School
3136
151m
Three Channel Flat
Dela Vedova Creek
273
XXII
79m
Donnybrook Stm
COAL REPORTED
228
465


239
Coal Flat
548m
CONTINUES NORTH
Bens Bridge
465
XXXI
152m
100
32
504
McIntosh Creek
Welshman Creek
Welshman
Pakihi
525m
31
704
Flaxbush
65
H
770m
Mountain Maid Creek
Creek
30
INANGAHUA FAULT
361
Thomson Creek
234
3137
72m
De Filippi Creek
449
647
29
BRUNNER
Cromwell Ck
Spring Creek
Boundary
M
1218m
V.H.F. Radio Repea
28
273
3136
151m
Three Channel Flat
Dela Vedova Creek
P.O.
Inangahua
School
XXII
79m
27
Dennibrook Stm
COAL REPORTED
Ram
306
CONTINUES NORTH
26



Inangahua
River
COAL REPORTED
SYNCLINE
INANGAHUA
Quarry
BROWN CREEK ROAD
Airstrip
Road-Rail Bridge
Aerial cable car
Inangahua Landing
3161
133m
3162
86m
232m
198m
Rough Creek
Gorgy Creek
Dee
Camp Creek
Coal Creek
Brown Creek
GLASGOW ANTICLINE
INANG
Bir
Bid
Tm
Tc
18 Reefton 22km
19
20
21
22
23
24
25
26
27
55′
E. Long 172°



INANGAHUA SYNCLINE
GLASGOW ANTICLINE
Rough Creek
Dee Creek
Gorgy Creek
Camp Creek
Brown Creek
Kokopo Crk
INANGAHUA EAST STATE FOREST
LYELL FAULT
COAL REPORTED
198m
571m
22
23
24
25
26
27
28
29
30
31
E. Long 172°00′